# ELEMENTARY GENERAL SCIENCE

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J. M. HARRISON

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# ELEMENTARY GENERAL SCIENCE

## BOOK I

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EDITED BY

**J. M. HARRISON**

SENIOR SCIENCE MASTER
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## BOOK I

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*Edited by* J. M. HARRISON
Book I
Book II
Book III

INTRODUCTORY SCIENCE FOR SECONDARY SCHOOLS

A PROGRESSIVE SCHOOL CHEMISTRY
*By* J. M. HARRISON
Introductory Course

*Printed in Great Britain by Neill & Co. Ltd., Edinburgh*

TO

J. E. BARTON

(HEADMASTER, BRISTOL GRAMMAR SCHOOL, 1917–1938)

# PREFACE TO THIRD EDITION

SINCE this book was first published in 1938, it has been reprinted many times. As the demand indicates that the book still retains its popularity, it was decided to produce a new edition and reset the type. Many diagrams have also been redrawn and some of the plates replaced by new material. The text has been revised in order to bring it up to date both as regards content and teaching practice. The views of teachers concerning the use of the millilitre as unit volume were sought, but opinion was so divided that it was finally decided to retain the cubic centimetre as the more suitable unit for beginners.

It is hoped that teachers in both Grammar Schools and Secondary Modern Schools will find the book useful as an introduction to science. The general character of the book remains unchanged, and its use along with copies of the previous edition should cause little difficulty.

In the production of this new edition, I have again been assisted by my former collaborators Mr. T. A. Morris, now retired, Dr. W. E. Flood, now of Birmingham University, and Mr. H. Dunnicliff. The sources of the half-tone illustrations are indicated on page xi; to all who so kindly supplied photographs and who gave permission for their reproduction, I offer my sincere thanks.

J. M. HARRISON.
*December* 1955.

BRISTOL GRAMMAR SCHOOL.

# PREFACE TO SECOND EDITION

THE continued popularity of this book has necessitated the production of a new edition. The opportunity has been taken to correct some minor errors and in a few places to rewrite the text. Sections have been added on the Applications of Bimetallic Strips, the Principle of the "Iron Lung", the Altimeter and Blood Transfusion. A few new diagrams have been introduced and new blocks for many of the original diagrams have been made.

J. M. H.

*February* 1952.

# PREFACE TO FIRST EDITION

SINCE the issue of the Report of the Panel of Investigators into School Certificate Examinations (1932), which recommended the inclusion of General Science as a subject for all candidates offering science, the adoption of this subject by schools has been widely discussed. There is much to be said for the teaching of Elementary General Science, especially to pupils who will not eventually specialize in science after the age of sixteen years.

This book provides a course in Physics, Chemistry and Biology, with special reference to Human Biology, which can be covered in approximately six year-periods by young pupils. The subject-matter is arranged so as to provide variety of topic and to show the relationship between the different branches of science.

The treatment is experimental, and it is hoped that there is adequate descriptive and explanatory matter to make the book a useful reader. The practical work to be done by the pupils in a course of General Science must necessarily be reduced. The experiments which they should perform are set in special type, and full instructions are given. All the experiments included in the book have been carefully tested. It is recognized that for some years teachers specially qualified in not more than two branches of science may be called upon to teach General Science. The footnotes and directions for certain demonstrations, which will be found in the Appendices, should prove helpful to such teachers.

For the most part the work is qualitative; the quantitative sections have been made simple, weighing by spring balance being used wherever possible. In this connection no attempt has been made to distinguish between mass and weight; the latter and more familiar term is accepted. Although chemical formulæ and equations have been introduced at an early stage, it is only intended that they should help to supply a picture of what takes place in the chemical changes studied.

Applications of acquired knowledge to problems of daily life are an important feature; it is assumed that in this connection many facts will have to be supplied as information.

Questions for some chapters only are included at the end of the book. These questions require thought and are suitable for homework; straightforward questions have been omitted in order to use the available space to the best advantage.

In the production of this book I have had the assistance of my colleagues Mr. T. A. Morris, B.Sc., Mr. H. Dunnicliff, M.A., and Mr. W. E. Flood, M.A., who have written major portions of the text. I accept responsibility for the general scheme of work and wish to express my thanks to my colleagues for adapting the text to this order of treatment.

Messrs. Longmans, Green & Co., Ltd., have very kindly allowed me to use a number of diagrams from various books published by them, but many of these diagrams have been specially redrawn for this book. My grateful thanks are due to Messrs. Blackie & Son, Ltd., Messrs. Basil Blackwell, the Oxford University Press, the Cambridge University Press, Messrs. W. and J. George, Ltd., for the loan of the diagrams indicated, also to the British Oxygen Co., Ltd., the Nitrate Corporation of Chile, Radiation, Ltd., and the Southern Railway for permission to reproduce photographs which they generously supplied.

J. M. H.
Bristol Grammar School.

# PLATES

PLATE Facing page

I. A—Frigate undergoing repairs in the floating dock at Harland and Wolff's, Belfast . . . . . . . 48
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B—Thermograph
*Photograph by William Gordon Davis*

II. A—Crystals of (i) copper sulphate, (ii) alum . . . . . 49
*Reproduced by permission of the British Museum (Natural History)*

B—Slow, sand filter-bed under construction, showing layers of shingle and sand
*Reproduced by permission of the Metropolitan Water Board*

III. A—Mined caliche being loaded into rail cars for transport to crushing machines . . . . . . . 64
*Reproduced by permission of the Nitrate Corporation of Chile Ltd.*

B—General view of works showing extraction tanks
*Reproduced by permission of the Nitrate Corporation of Chile Ltd.*

IV. The Tadpole . . . . . . . . . 65
*From H. Munro Fox, "Biology," by permission of the University Press, Cambridge*

V. A—Patient in a plastic "iron lung" . . . . . . 128
*Reproduced by permission of British Celanese Ltd.*

B—Guericke's Magdeburg hemispheres experiment
*Reproduced by permission of the Science Museum, Crown Copyright Reserved*

VI. A—Oil-drum crushed by atmospheric pressure . . . . 129

B—Barograph
*Reproduced by permission of Messrs. Negretti & Zambra Ltd.*

C—Oxygen Machine Cutting
*Reproduced by permission of the British Oxygen Co. Ltd.*

VII. A—Babies in oxygen-tents at Westminster Hospital . . . 144
*Photograph by Keystone Press Agency Ltd.*

B—Team equipped with mine rescue apparatus crawling along roadway
*Photograph by Picture Post Library*

VIII. A—Oxy-hydrogen under-water cutting . . . . . . 145
*Reproduced by permission of the British Oxygen Co. Ltd.*

B—Oxy-acetylene welding
*Reproduced by permission of the British Oxygen Co. Ltd.*

# CONTENTS

CHAPTER | PAGE

Preface . . . . . . . . . . vii

Introduction . . . . . . . . . xiv

1. The First Things in the Study of Physics . . . . 1
2. Density, Upthrust and Flotation . . . . . . 11
3. Fire, Heat and Expansion . . . . . . 23
4. Thermometers and Temperature Measurement . . 30
5. Expansion and Contraction in Daily Life . . . . 39
6. How we separate Substances from Natural Mixtures . 51
7. How we recognize Substances and sort them into Classes 62
8. Living Things. How Plants differ from Animals. A Simple Animal and a Simple Plant . . . . 71
9. The Parts of a Flowering Plant . . . . . . 79
10. A Description of the Development of a Frog, and of its Habits and Food . . . . . . . . 86
11. The Skeleton and its Importance. A Comparison between Ourselves and a Frog. Muscles and Movement . . . . . . . . . 93
12. Atoms . . . . . . . . . . 111
13. A Simple Study of Acids and Alkalies . . . . 116
14. The Air and its Physical Behaviour . . . . . 121
15. The Chief Substances found in the Atmosphere . . 131
16. Oxygen and its connection with Burning. Nitrogen . 138

CHAPTER PAGE
17. Blood . . . . . . . . . . 151
18. The Respiration of Animals and Plants . . . 160
19. Some Simple Heat Measurements. How we regulate our Temperature . . . . . . . 170
20. The Transmission of Heat . . . . . . 185
Appendix A . . . . . . . . . 207
Appendix B . . . . . . . . . 211
Appendix C . . . . . . . . . 211
Questions . . . . . . . . . 216
Index . . . . . . . . . . 223

# INTRODUCTION

## What do we mean by Science?

It is difficult to give a simple answer to this question. You will understand what science is about if we deal with the question in a roundabout way. You know that children are always asking questions about all kinds of things. Just consider an ordinary day in your life; think of some common things and happenings you come across, and ask yourself questions about them.

Let us suppose the time of the year is early spring. You get out of bed and notice that it is rather cold. Perhaps you are fortunate enough to have a gas-fire in your room, which has just been lit for you. At once your questions begin. "What is coal-gas?" "How is it made?" "What happens when it burns?" "Why does it give out heat when burning?" "What is heat?" Looking out of the window, you notice that the ground is covered with hoar frost. "What is hoar frost?" "How is it formed?" You must get on, so you proceed to wash. "Where does water come from?" "What is it made of?" "What is soap?" "How is it made?" "How does soap help to remove dirt?"

You begin to dress and think about clothes. Wool, cotton and artificial silk or rayon are used in making clothes. You know that wool is obtained from sheep, and that cotton is a vegetable fabric, but you say: "What is artificial silk?" "How is it made?" Your under-clothing is still mostly woollen to keep you warm. "Why is wool so much warmer than cotton?" You know that boots and shoes are made of leather and that the latter is made from the hides of certain animals. "How is the hair removed?" "How is the soft hide made into tough leather?"

You go down to breakfast feeling very hungry. "Why is it necessary to eat?" We nearly always eat bread. Boys and girls in the north of England will know how it is made. "What happens to the bread and other kinds of food which we eat?" You have been told to chew your food well. "What is the reason for this?" You know that you have an organ called the stomach into which the food passes. "What does the stomach do, i.e. what is its function?" You are also aware that you possess other organs, e.g. heart, lungs and liver. "What are they for?"

Breakfast being over, father charges his pipe and lights the tobacco. "What is there in the head of a match?" "Why does it flare up when stroked on the side of the box?" "Why are some matches called safety matches?" It is nearly time you were off to school, so you trot upstairs to clean your teeth. You know that your teeth will decay if you do not take care of them. "What causes teeth to decay?" "If decay has started, why do they ache?"

You set out for school, walking. "What causes our limbs to move as we wish them to do?" Perhaps you have a journey by motor-bus. This is run by a petrol-engine or possibly a Diesel-engine. "What is petrol?" "Where does it come from?" "How does the engine work?"

In school you sit at a desk; you use paper and ink, perhaps a pencil and rubber. "How does a tree produce wood?" "How is ink made?" "What is the 'lead' in your pencil made of?" "What is rubber?"

After morning school, your body needs more food. The sun is now shining brightly and you find that it is much warmer outside. "How does heat from the sun reach us?" On your way home when school is over, if you pass through the country you notice that the buds on the trees are beginning to burst, and that the birds are singing again. "Why do these things happen in spring?"

Soon after tea it is dark. "Why do we have day and night?" "Why do they vary in length throughout the year?" You switch on the electric light. "What is electricity?" "What is there in the bulb which produces the light?" "What is a gas-filled lamp?" You get on with your homework and only too soon it is time for bed. Before getting in, you have a last look outside; the moon and the stars are shining brightly. "Why does the moon change in appearance during each month?" "What exactly is a star?" "How far away are the various heavenly bodies?"

These are but a few of the questions which any boy or girl might ask. The knowledge we have obtained in attempting to answer thousands of similar questions is what we mean by Natural Science. We do not know the answers to all these questions. For instance, it is not possible to say what electricity is, although we know a good deal about it. Scientists are constantly trying to find better answers to awkward questions; they are getting to know more about nature year by year; they are inventing new instruments and machines, and making new substances (for example plastics). These so-called plastics are not found naturally; they are formed as the result of complex chemical reactions. Plastics are taking the place of wood, metal, glass, china and fabrics in the manufacture of ash-trays, switches, plugs, lamp-shades, cups and saucers, trays, vases, buttons, buckles, stockings, films, gramophone records, fountain pens, tooth-brushes and many other objects in everyday use. In these books we want you to learn something about Natural Science, especially those portions of it which affect your daily life.

## How is scientific knowledge obtained?

The facts of science are obtained by making observations, i.e. noticing very carefully by means of our senses. To aid our senses we often use instruments. Thus, astronomers use powerful telescopes to study the heavenly bodies, while biologists have powerful microscopes for examining tiny creatures and for investigating the structure of living matter.

Whereas in astronomy we can only watch what is happening, in certain other sciences, e.g. physics and chemistry, we perform experiments. For instance, in chemistry we can try to get substances to act upon each other; in this way we can make many substances which are not found naturally. Whenever we experiment, we make observations and thus learn new facts.

The questions you might ask during your ordinary day are a very mixed lot, dealing with varying topics from coal-gas to the moon, digestion to wireless, and matches to buds and birds. Scientists do not study these topics in a higgledy-piggledy fashion; they sort them into related groups or special sciences. In these introductory books we shall deal chiefly with portions of elementary physics, chemistry and biology, and try to show some of the relationships between these sciences.

## CHAPTER 1

# THE FIRST THINGS IN THE STUDY OF PHYSICS

### Introductory

Scientific knowledge has accumulated to such an extent that it is, for most purposes, convenient to divide the whole of it into separate sections (or branches). One of these is known as physics. This word is derived from the Greek *physis*, meaning nature, but not all science which deals with nature can now be classified as physics. To-day, this branch of science deals with our knowledge of natural events (or phenomena) in one particular way: it is concerned with the action of forces, of many types and from many different sources, upon the different kinds of substances which occur in nature, or which can be made from these by man. Let us first look at these substances. Whether visible or not, they occupy space and have weight, and are given the common name of **matter.**

### The states of matter

If you were shown a number of common substances, such as coal, brass, glass, water, petrol and glycerine, and told to name each one, you would not have much difficulty, because you are already aware of certain peculiarities possessed by each, by means of which you distinguish it from the others. These **peculiarities** of a substance are known as the **properties** of the substance. You may thus distinguish coal from brass by the property of its colour, water from glycerine by the property of its easy flow from one vessel to another, petrol from water by the property of odour in one and lack of it in the other, and so on.

Now if you examine the substances mentioned above, you will find that before distinguishing each one by some special property, each can be placed in one of two groups. To do this you make use of the property of flowing. If the substance will not flow, e.g. coal, brass, glass, it is placed in the first group; if it will flow it is placed in the second. All substances in the first group are known as **solids,** all in the second group as **fluids,** and the distinction between these is at once fixed by the meaning of the word, fluid. **A fluid is a form of matter which will flow.**

As, however, such different substances as water, petrol, air and coal-gas flow, another property is considered, so that you may separate all fluids further into two groups. Anyone who has used a cycle pump will realize that air can be compressed by a force exerted by a child. Coal-gas, like air, can be easily compressed; in fact, it is under slight pressure in the supply mains, and that is why it flows out quickly when you turn on a gas tap. It is impossible, as far as the eye can see, to detect any change in size when attempts are made to squeeze a quantity of water or glycerine into a smaller space.

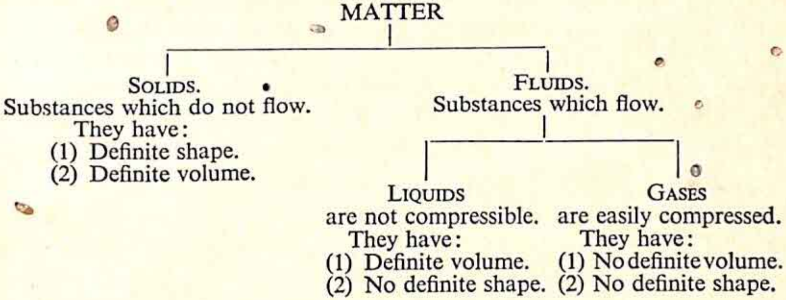
Those fluids which are easily compressed are separated from those which cannot be compressed; the former are called **gases,** the latter **liquids.** Thus, by using the properties of flowing and compressibility, you may divide all kinds of matter into **solids, liquids** and **gases;** these are generally referred to as the **three states of matter.**

Any solid will retain its shape unless you deliberately deform it by using force, and so it is said to be rigid or to possess the property of rigidity. It is this property which distinguishes all solids from other forms of matter. Liquids and gases always require containing vessels, but you may distinguish these two groups of fluids by the following contrasts:

(i) Almost any quantity of gas can fill a given vessel and if some be withdrawn, the remainder expands to fill the vessel.

(ii) The same vessel will hold only a definite quantity of any liquid, and if less than this quantity be placed in the vessel, it occupies the lowest available part of that vessel.

Briefly then we may summarize as under:



MATTER

SOLIDS.
Substances which do not flow.
They have:
(1) Definite shape.
(2) Definite volume.

FLUIDS.
Substances which flow.

LIQUIDS
are not compressible.
They have:
(1) Definite volume.
(2) No definite shape.

GASES
are easily compressed.
They have:
(1) No definite volume.
(2) No definite shape.

## In the laboratory

Having learned to classify substances according to the three states of matter, you are ready to examine the action of various natural forces upon them. As a result of any examination, you should record what has happened and attempt to state why it has happened. Further, this record will be more useful if you have been able to fix your ideas by means of numerical results obtained from actual measurements. For example, lead is a heavy metal, but you have a better idea of its heaviness if you know that 1 cu. ft. of lead weighs 700 lb. This numerical form of statement is the best, and because this is so, you must learn to make properly such measurements as are required.

The **laboratory** in which you carry out your **experiments** is really a kind of **workshop**, and the **tools** which you use for this purpose are called **apparatus.** The tools are not equally good, and will not always yield equally satisfying results. If your results are not as good as you expected, or would like them to be, do not blame the apparatus; instead, consider carefully whether you have made the best use of it.

The **first exercises in measurements** are concerned with lengths, areas and volumes, the results usually being expressed in centimetres (cm.), square centimetres (sq. cm.), and cubic centimetres (c.c.).[1] If you compare the laboratory metre and half-metre scales with your own foot-rule, you will note two differences. On your foot-rule the edges are bevelled and the zero mark is not quite at the end of the wood. The laboratory scale has neither of these features; consequently you cannot use it in the same way as you would use your own rule, and a glance at the accompanying diagrams (Fig. 1), showing the correct and incorrect measurement of the length of a rectangle will soon convince you of the reasons.

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[1] The English units of length, the yard, the foot and the inch are seldom used in the laboratory.

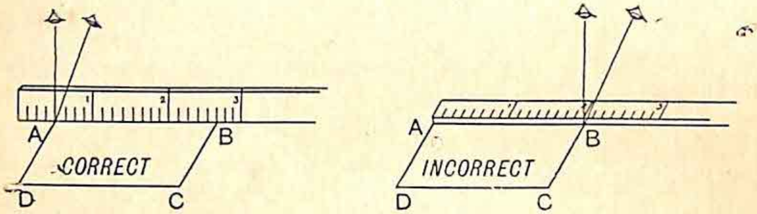

FIG. 1

Having learned to measure straight lengths properly, it is a simple task to determine the **areas** of rectangles and triangles, of circles and cylinders and even of spheres. From the measurements made, the required area is calculated by using the ordinary arithmetical rules. (See Appendix A, p. 207.) The problem of measuring the radius of a cylinder or sphere may worry you, but a glance at Fig. 2 should help you to perform the operation.

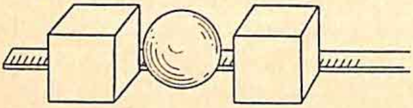

FIG. 2

The **volumes** of prisms, pyramids and spheres may be found by measurement and calculation. (See Appendix A, p. 208.) This is a laborious method, and generally it is rejected in favour of others, one of which you will learn immediately; the other will be investigated later (see p. 18).

## Volume measurement of liquids

As liquids take the shape of the containing vessel, you will only be concerned with their volumes, and for this measurement certain vessels specially designed and graduated are in use. They are:

(1) **The pipette** (Fig. 3), measuring one definite volume of relatively small magnitude, e.g. 10, 20 or 25 c.c.

(2) **The graduated flask** (Fig. 4) also measuring one definite quantity but of greater volume than is usual with a pipette, e.g. 100, 250, 500 and 1000 c.c.

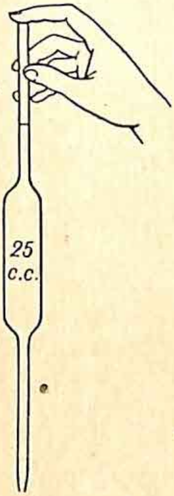

FIG. 3.—Pipette

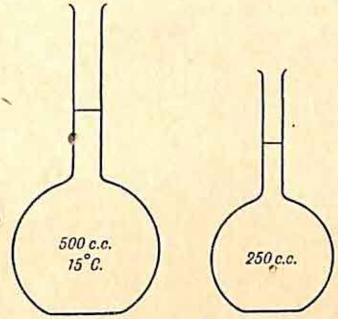

FIG. 4

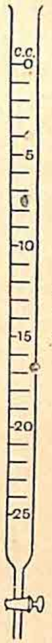

FIG. 5.—Burette

(3) **The burette** (Fig. 5), graduated in tenths of a c.c. to measure any volume up to 25 or 50 c.c.

(4) **The graduated cylinder** (Fig. 6) graduated usually in 100 (or 200) subdivisions to measure larger volumes, the standard sizes recording up to 100, 250, 500 or 1000 c.c.

*A unit of liquid volume in common use is the litre. This is the volume of* 1 *kilogram of water at* 4° *C.* (*p.* 50). *For elementary work, this is practically the same as* 1000 *c.c., so that* $\frac{1}{1000}$ *litre,* or 1 *millilitre, may be accepted as* 1 *c.c. It is now usual to mark these vessels in millilitres (ml.) instead of c.c.*

If you look at the liquid surface in any of these vessels, you will note that it is not flat; for most liquids in common use (e.g. water, alcohol) it is curved downwards from the side towards the middle. The graduations on all these vessels are placed in positions so that a correct reading is obtained by having the bottom of the curved surface, called the **meniscus**, level with the mark (Fig. 7). (*Note the position of the eye to test this level.*)

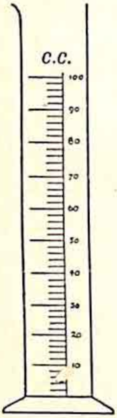

FIG. 6

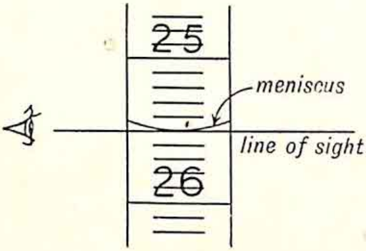

FIG. 7

In addition to being used for measuring volumes of liquid, the burette and graduated cylinder provide a ready means of finding the volume of a solid. After choosing the vessel appropriate in size to the solid in use, some liquid, usually water, is poured in, and the level of its meniscus read. The solid is then lowered into the liquid until completely submerged, and the new level of the meniscus read. You should now be able to answer these questions.

(i) How many c.c. of liquid have been displaced by the solid?
(ii) What is the volume of the solid?

Sometimes the object in use will not go into a burette or measuring cylinder; additional apparatus is then needed. This is an overflow jar (Figs. 8, 9) and it is placed so that the liquid, already at the level of the spout, overflows into a measuring vessel as the solid is introduced into and submerged by the liquid. Two readings from the measuring vessel enable you to determine the required volume.

This method is so quick and requires so little calculation, that it is good policy to adopt it for an object even when its volume could be obtained by ordinary arithmetical methods.

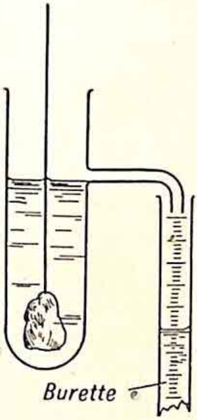

FIG. 8

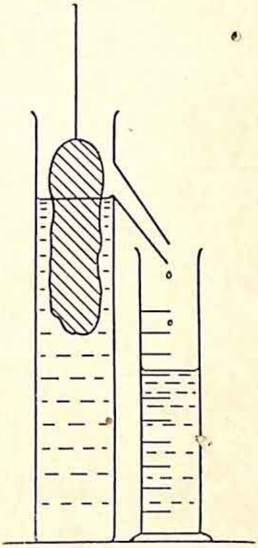

FIG. 9

## On weighing substances

You must now turn your attention to the problem of weighing a substance. This is done by using one of the following:

(i) **A spring balance** (Figs. 10, 11).
(ii) **A lever balance** (Fig. 12).
(iii) **A chemical** (or beam) **balance** (Appendix A, p. 208, Fig. 150).

At the outset you must realize that there is a great difference between these three pieces of apparatus. The **spring balance** is strong and sturdy: it is not suitable for weighing small quantities of substances, but large quantities, as you have seen in shops and at home, can be weighed quickly and with fair accuracy. Before weighing a substance, you try to estimate roughly how heavy it is, and then choose a spring balance that will enable you to obtain a value as accurately as possible, e.g. if you estimate the weight of the substance to be about 200 gm., it is better to use a spring balance graduated to take a total load of 250 gm. than one graduated to a maximum load of 1000 gm.

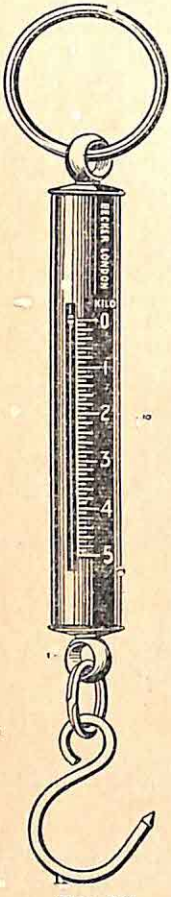

FIG. 10

The **lever balance** is equally satisfactory for quick weighing and is now often used as a substitute for the compression type of spring balance shown in Fig. 11. The "Butchart"[1] rapid weighing balance illustrated in Fig. 12 gives a range of 0–200 gm., with graduations of 1 gm., or a range of 0–1000 gm., with 5 gm. graduations.

The **chemical balance** is a far more refined piece of apparatus, and, because of this, it must have much greater care bestowed upon it in use. The rules for its use, given in Appendix A, p. 210, are important and should receive the closest attention. When the beam of the balance is fully raised (see *Rule* 9), it swings very slowly; moreover, it must be lowered every time any weight, however small, is added to or removed from the pan. Consequently, weighing a substance on a chemical balance is a slow operation, and although you must learn to weigh accurately in a reasonable time, it is as well to remember that too great haste

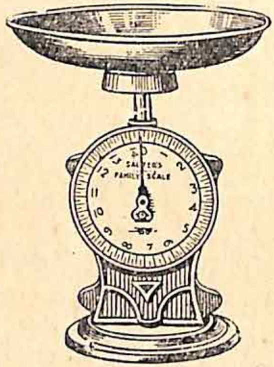

FIG. 11

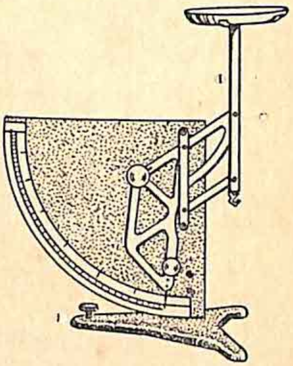

FIG. 12

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[1] This balance is supplied by W. B. Nicolson Ltd., Thornliebank Industrial Estate, Glasgow.

generally leads to (*a*) bad results, (*b*) damage to the balance. The refinement of the balance which you use can be demonstrated by the following simple experiment.

Expt. 1.—*To test the refinement of a chemical balance.*

Weigh a piece of paper. Remove the paper from the pan, write your name and address in ink upon it, and leave to dry. Replace the paper on the pan, weigh again, and find the increase due to the dried ink.

## Exercises for practice in the use of capacity vessels and the balance

Expt. 2.—*To find the weight of* 1 *c.c. of water and other common liquids.*

Apparatus: Beam balance and weights, 2 beakers, pipette (25 c.c.), water, methylated spirits, saturated brine, copper sulphate solution, etc.

Weigh one beaker, and pour some water into the other. By means of the pipette, transfer 25 c.c. of water to the weighed beaker. Weigh this beaker again and calculate (*a*) the weight of 25 c.c. of water, (*b*) the weight of 1 c.c. of water. Repeat the experiment for the other liquids.

Expt. 3.—*To find the weight of* 1 *c.c. of water and other common liquids* (alternative method).

Apparatus: Compression spring balance or lever balance, graduated cylinder, liquids as in Expt. 2.

Weigh the graduated cylinder on the spring balance, pour water into the cylinder, read the volume taken and weigh again on the spring balance. Hence calculate the weight of 1 c.c. of water. Repeat for other liquids as before. In this case, we may add mercury to the list of liquids for it is easily poured from one vessel into another. Without weighing it, we can tell it is a heavy liquid and therefore the smallest graduated cylinder (for volumes up to 100 c.c.) should be used. You will observe that with mercury the meniscus is curved upwards; in this case the reading is taken at the top of the curve.

Expt. 4.—*To find the weight of* 1 *c.c. of wood.*

*Note*. By using wooden blocks of various regular, geometrical shapes this exercise may be approached in two ways. If the blocks are made from the same kind of wood, repetition of the experiment will provide a check on the accuracy of your work. If the blocks are made from different kinds of wood, you will be able to ascertain whether equal volumes of all kinds of wood are equally heavy.

Apparatus: Beam balance and weights, half-metre scale, cube (or rectangular prism), cylinder, cone and sphere of wood.

Starting with the cube (or prism) measure the length, breadth and depth, and calculate the volume in c.c. Weigh the wood and then calculate the weight of 1 c.c. of it. Repeat for the cylinder and the cone for each of which you need the height, radius and weight, and for the sphere for which only the radius and weight are required. (See Fig. 2 and Appendix p. 208.)

EXPT. 5.—*To find the weight of* 1 *c.c. of brass and other common solids* (alternative method).

Apparatus: Spring balance or lever balance, graduated cylinder, overflow jar, lumps of brass, copper, aluminium, marble, etc.

Weigh the brass and find its volume either by immersing it (if possible) in water in the graduated cylinder (p. 6) or by using an overflow jar and catching the overflow in the cylinder (p. 7, Fig. 9). Then calculate the weight of 1 c.c. of this metal.

Repeat the experiment for the other materials provided.

## CHAPTER 2

# DENSITY, UPTHRUST AND FLOTATION

### Comparing the "heaviness" of substances

You are well aware that a lump of iron, or a common house-brick, or even a small pebble sinks easily in water. If asked for the reason, you will reply: "Because the iron (or brick or pebble) is heavier than water." Also you will say that wood is lighter than water if a block of it floats in water. Such answers are not scientifically exact, because in each case you have not stated how much iron, how much wood and how much water were considered when making the comparison.

The practical exercises of the previous chapter give the weight of 1 c.c. of a few common liquids and solids, and any two of these substances could be fairly compared in heaviness because you have the same volume, namely 1 c.c., of each. This equality of volume is always necessary when comparisons of this kind are being made. It is not always necessary to specify 1 c.c. of each substance; any volume may be taken, e.g. 25 c.c. of water and of brine from a pipette, so long as it is the same for both.

### The weight in gm. per c.c. (or in lb. per cu. ft.) of a substance is the density of that substance

Comparisons of the weights of equal volumes, whether 1 c.c. or more, are really comparisons of densities. When you said that iron was heavier, or that wood was lighter, than water, you should have said that iron has a greater density and wood a less density than water. More briefly we say; iron is denser than water, wood is less dense then water.

Further, from the values previously obtained you are able to say, not only that iron is denser than water, but, in addition, you can state just how many times 1 c.c. (or 1 cu. ft.) of iron is as heavy as 1 c.c. (or 1 cu. ft.) of water. It is not even necessary to specify 1 c.c. of each; any volume may be selected in making this comparison, so long as it is clearly understood that it must be the same for both substances. This numerical comparison of heaviness is making a statement of the **specific gravity** (or relative density) of the substance, and for all practical purposes, solid and liquid substances are compared only with water.

**Thus** $$\textbf{Density}=\frac{\textbf{Weight}}{\textbf{Volume}}$$

**but** $$\textbf{Specific Gravity}=\frac{\textbf{Weight of substance}}{\textbf{Weight of equal volume of water}}$$

It is important to note that the number expressing the density of a substance varies according to the system of measurement; but that the number expressing the specific gravity is the same for all places and all systems of units. So long as you weigh both substances in gm., or in lb., in ozs., or in weights of your own design and make, the result will not vary.

Since the density of water is 1 gm. per c.c., it is evident that the numbers expressing (i) the density in metric units and (ii) the specific gravity of a particular substance are the same, but a brief examination of corresponding values in the English system will soon show that density and specific gravity have quite separate and distinct meanings. Thus:

$$\textbf{In metric units}\left\{\begin{array}{l}\text{the density of water is 1 gm. per c.c.}\\ \text{the density of gold is 19·2 gm. per c.c.}\\ \therefore\text{the specific gravity of gold is 19·2.}\end{array}\right.$$

**but**

$$\textbf{In English units}\left\{\begin{array}{l}\text{the density of water is 62·5 lb. per cu. ft.}\\ \text{the density of gold is 1200 lb. per cu. ft.}\\ \therefore\text{the specific gravity of gold is } \dfrac{1200}{62\cdot5}=19\cdot2.\end{array}\right.$$

The experiments at the end of the previous chapter (pp. 9, 10) were therefore merely determinations of density. They can always be repeated when the density of any other substance is required, and as we have determined the density of water, the specific gravity of any substance can be written down at once.

## Support by liquids for the weight of a substance

Those of you who are swimmers are aware of the supporting effect of the water, and some who learned to swim in sea-water may still remember their surprise on finding that fresh water did not support them quite so well as sea-water. Other objects, such as ships and rafts, which float, are supported by the water in the same way as our own bodies.

You have now to consider the case of an object which does not float. Clearly, after it has sunk it is supported by the solid surface at the bottom of the liquid, and your enquiry must therefore be directed to observations when the object has liquid underneath it. In such circumstances it may be

(1) completely immersed in the liquid, or
(2) partly immersed in the liquid;

but it will always need some additional support, usually a suspension, to prevent it from sinking.

## Upthrust

If a solid is suspended from a spring balance, its weight being recorded, and then gradually immersed in water, the reading of the balance decreases all the time during which the immersion takes place. It reaches its final value when immersion is complete (Fig. 13), and no further decrease is noted when the solid is lowered in the water to a greater depth. The weight of the solid appears to be decreased by the process of immersion, whether partial or complete. Consequently it is clear that in this case, as in that of a floating object, the liquid provides some support for the solid, although insufficient to keep it afloat. This supporting force is called the **upthrust of the liquid**, the final reading on the spring balance is called the apparent weight of the solid, and the **difference between the true weight and apparent weight measures the upthrust for complete immersion.**

You must now proceed to determine what factors control the size of the upthrust which is exerted by:

(*a*) Various liquids on the same solid.
(*b*) The same liquid on solids of different size.
(*c*) The same liquid on solids of the same size but of different material.

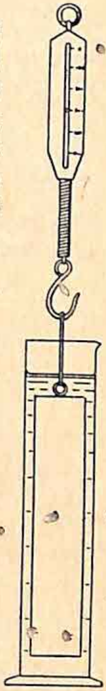

FIG. 13

EXPT. 1.—*How does the upthrust vary when the liquid is changed?*

Apparatus: Stand and clamp, aluminium cylinder,[1] spring balance (reading to 500 gm.), deep cylindrical jar, water and other liquids of known density (p. 9).

Weigh the cylinder in air, and successively in the various liquids supplied. Be sure, in every case, that the cylinder is completely immersed, does not touch either the side or bottom of the jar, and that no air bubbles are sticking to it. Enter the readings obtained in a table as follows:—

| Liquid used | Actual weight of cylinder | Apparent weight in liquid | Upthrust of liquid | Density of liquid |
|---|---|---|---|---|
| Water . . | 475 gm. | 300 gm. | 175 gm. | 1·0 gm./c.c. |
| Brine . . . | 475 „ | | | |
| "Meths." . . | 475 „ | | | |

Compare the values in the last two columns carefully, and write down a clear statement of what they prove.

EXPT. 2.—*How does the upthrust of the same liquid vary when the size of the solid immersed is changed?*

Apparatus: Stand and clamp, 2 aluminium cylinders[2] of different size, spring balance (reading to 500 gm.), deep cylindrical jar, water, brine.

Weigh each cylinder in air and immersed in water, taking the same precautions as in the previous experiment. Record your results thus:

Weight of **large** cylinder in air = gm.
„ „ water = „
∴ Upthrust on large cylinder = „
Weight of **small** cylinder in air = „
„ „ water = „
∴ Upthrust on small cylinder = „

Compare the upthrusts. What do your figures prove?

Repeat the experiment completely, using some other liquid, e.g. brine, instead of water, to find out if your statement is still true.

EXPT. 3.—*How does the upthrust of the same liquid vary when solids of equal volume, but of different material are immersed in it?*

Apparatus: Stand and clamp, aluminium and brass cylinders[3] of same dimensions, spring balance (reading to 1000 gm.), water and jar as before.

---

[1] A suitable size is: height 8 in., diameter 1¼ in., the weight of which is about 450 gm.

[2] Using the cylinder from Expt. 1, a suitable size for the second one is height 5 in., diameter 1¼ in. It can be cut from same stock rod.

[3] Useful dimensions for these cylinders, height 5 in., diameter 1¼ in.

The procedure and records to be made are the same as in the previous experiment. Compare the upthrusts on the aluminium and brass cylinders. What does this experiment prove?

In the experiments just performed, you have paid attention to the density of the liquid, to the size of the solid, and even to a change of material of the solid used. You may have noticed that in each case, some of the liquid was displaced, but you did not take any measurements either in volume or weight of the displacement. This must be the aim of the next experiment. As you have been concerned with the weight and change of weight of the immersed solid, it is appropriate to consider the weight of the displaced liquid rather than its volume.

EXPT. 4.—*Is there any relationship between the upthrust on an immersed solid and the weight of liquid which that solid displaces?*

Apparatus: As for Expt. 1 (p. 14) and a beaker, compression spring balance and large overflow jar (Fig. 9) appropriate to immerse completely the aluminium cylinder in the liquid used.

Pour water into the overflow jar, catching any outflowing surplus in the beaker. Empty the beaker, weigh it and replace it under the spout. Weigh the aluminium cylinder in air, then carefully lower it, still suspended from the spring balance, into the overflow jar until it is *completely immersed* (Fig. 14) and collect the overflow of water in the beaker. With the cylinder thus immersed, read the spring balance and calculate the upthrust due to the water. Then weigh the beaker with the collected water and calculate the weight of water displaced by the cylinder. Compare this weight of water with the upthrust.

Repeat the whole process using brine and then "meths" instead of water and in each case compare the weight of liquid displaced with the upthrust due to that liquid. What conclusion do you draw from these comparisons?

Repeat the experiment once more, with any liquid, lowering the cylinder until it is only *partly immersed* and compare again the upthrust on the partly immersed cylinder with the weight of liquid displaced by it.

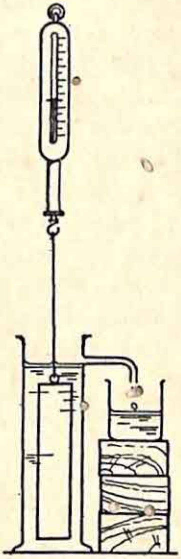

FIG. 14

You may regard the conclusion to this experiment as a **scientific law,** actually the first of many with which you will become acquainted.

## The upthrust on a floating body

Clearly a body which floats is completely supported by the liquid, and therefore appears to lose all its weight. The upthrust is therefore equal to the true weight of the floating body. Does it displace, under these conditions, a weight of liquid equal to its own weight?

The answer is readily supplied by a simple variation of Expt. 4. After weighing the body,[1] it is detached from the spring balance, lowered carefully into the overflow jar and released to float freely. The weight of the displaced liquid is then compared with the weight of the body which was wholly supported by the liquid.

## The Principle of Archimedes

The law relating to the upthrust of a liquid was first stated, in the third century B.C., by Archimedes, a Greek of Syracuse, and is one of the earliest exact expressions in the history of science. It may be stated thus:

**When a body is completely or partly immersed in a fluid, the fluid exerts, on the body, an upthrust which is equal to the weight of the fluid displaced.**[2]

You should now refer to the statements you made in Expts. 1, 2 and 3 above, and decide whether they are true for bodies which float or whether they need modifying.

## What becomes of the "lost weight"?

Owing to the upthrust of the liquid, the weight of a body, immersed in it or floating on it, appears to have decreased. Although the pull on the spring has certainly diminished, the **earth's actual pull** on the body cannot be less. We have therefore to account for the remainder of the downward pull which is not registered on the spring balance.

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[1] A long sealed glass tube (12 in. long, 1 in. diameter), loaded at the bottom so as to float upright serves very well.

[2] Application to gases is discussed in Book II.

A beaker containing sufficient water to immerse a lump of metal is placed on the pan of a compression spring balance and its weight noted. The lump of metal is suspended from an ordinary spring balance and its weight read. The spring balance and metal are suspended from an independent support and this is lowered until the metal is completely immersed (Fig. 15) in the water. Both spring balances are read and the upthrust compared with the increase recorded by the compression balance.

This experiment clearly shows that the part of the true weight of the body, not registered by the supporting spring balance, is transferred through the liquid on to the base of the vessel holding it. It is usually called the downthrust of the immersed solid upon the liquid.

A slight modification of this experiment shows that the same conclusion is obtained for floating bodies.

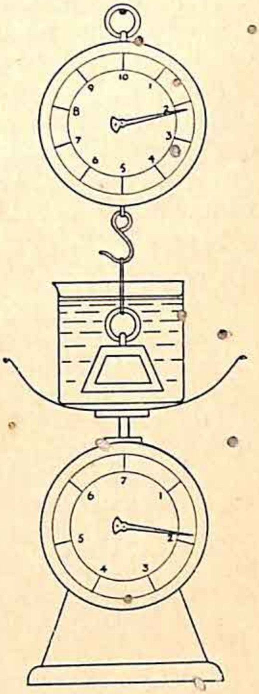

FIG. 15

## Applications of Archimedes' principle

These applications are considered in the following five problems which are based upon the experiments which led to your first knowledge of the principle.

*Problem* 1.—*To find the density of a solid which is denser than water.* The experimental process repeats the first part of Expt. 1. If you refer to the table (p. 14), the first line provides all the information required, and you can calculate the density as follows:—

Weight of cylinder (aluminium) =475 gm.
Upthrust of water =175 gm.
∴ Weight of water displaced =175 gm.
∴ Volume of water displaced =175 c.c.
∴ Volume of aluminium =175 c.c.

$$\therefore \text{Density of aluminium} = \frac{\text{Weight}}{\text{Volume}} = \frac{475 \text{ gm.}}{175 \text{ c.c.}}$$

$$= 2{\cdot}71 \text{ gm. per c.c.}$$

Similarly, you can find the density of any other solid, even one of irregular shape.

You should notice also, that this experiment provides another method for finding the volume of a solid—the method in fact which was promised (p. 4).

*Problem* 2.—*To find the specific gravity of a solid.* The experimental work is the same as that of the previous problem but the argument requires the weight of an equal volume of water instead of the volume of the solid. This follows at once from the weight of water displaced (175 gm., above). Hence:

Specific gravity of aluminium

$$=\frac{\text{Weight of metal}}{\text{Weight of equal volume of water}}=\frac{475\text{ gm.}}{175\text{ gm.}}$$

=2·71 (numerically the same as the density).

*Problem* 3.—*To find the density of a liquid.* Consider the following experimental readings, again based on Expt. 1:

Weight of metal cylinder in air =272 gm.
Weight of metal cylinder in water =172 ,,
Weight of metal cylinder in another liquid=158 ,,

Now answer these questions carefully:

What is the upthrust of the water?
What is the volume of water displaced?
What is the upthrust of the liquid?
What is the weight of the liquid displaced?
What is the volume of the liquid displaced?

How would you use these answers to calculate the density of the liquid?

*Problem* 4.—*To find the density* (*or specific gravity*) *of a floating body.* As before, the weight of the body will be required. This could be obtained in the usual way, but, as the following experimental work will show, it is interesting to note that the weight of a body which floats in water may be obtained without the use of any kind of balance.

It is first floated in water in a graduated cylinder (or an overflow jar) and the volume of displaced water found. Suppose this is 18 c.c. Then:

Weight of water displaced = 18 gm.
∴ Upthrust of water = 18 gm.
∴ Weight of floating body = 18 gm. (Archimedes' principle.)

The volume of the body is then found by pushing it down in the measuring cylinder (or overflow jar), until it is just completely immersed in the water. The density is then calculated in the usual way.

Or, if you want the specific gravity, you can find the weight of an equal volume of water, since you know the volume of the body, and then work out:

$$\frac{\text{Weight of floating body}}{\text{Weight of equal volume of water}}$$

This determination of specific gravity is particularly instructive because it will show that for any body, *floating in water*, the **fraction of its volume which is under water-level is equal to the specific gravity of the body.**

*Problem* 5.—*To find the density of a liquid by using a floating body.* The displacement of water by the floating body is first found. Suppose, as in problem 4, it is 18 c.c. The displacement of the liquid by this *same floating body* is then found. Suppose it is 20 c.c.

In each case, the weight of water or of the liquid displaced is equal to the weight of the floating body. This has been shown to be 18 gm. Thus the weight of liquid displaced is 18 gm. Since its volume is 20 c.c., its density is 0·9 gm. per c.c.

### The common hydrometer.

The result just obtained shows how a floating body may be used to record densities of liquids. When used for this purpose, it is called a hydrometer. In its simplest form it is a narrow cylinder, e.g. a test-tube, loaded at the bottom with lead shot or mercury so as to float upright in the liquids to be tested. Usually it carries a scale from which the density in gm. per c.c. or the specific gravity may be read directly.

EXPT. 5.—*To make and graduate a simple hydrometer.*

Apparatus: Flat-bottomed test-tube (about 5 in. × $\frac{5}{8}$ in.), lead shot, strip of graph paper, small gas-jar, liquids (water, brine, etc.) of known density.[1]

Cut a strip of graph paper slightly longer than the test-tube and mount it lengthwise in the tube. As it will be necessary from time to time to remove and replace the paper, *and each time it must be replaced in exactly the same position*, its position in the tube must be marked.

Pour some of the densest liquid into the gas-jar until it is nearly full. Float the tube in the liquid and, without disturbing the strip of paper, add just enough lead shot to make it vertical. Take a horizontal, sighting line at the level of the liquid and note the position of this level on the paper; remove the paper and on it draw a short line at the level just observed. Replace the paper exactly as before and test the line as drawn. When this test is completed successfully, write the density of the liquid used at the end of the line.

Remove the tube, dry it and replace the paper. Without changing the load of lead shot, repeat the observation, testing and numbering of a line for each of the other liquids, using them preferably in descending order of density.

This simple hydrometer is too uniform in design to be really serviceable in matters of range and accuracy. Most of its length is immersed before it floats vertically in the densest liquid, and the fraction left for further immersion in less dense liquids is so small that the marks are too close together for accurate observation.

To overcome this limitation, the instrument is usually shaped as shown in Fig. 16. Most of the displacement is produced by the central, air-filled bulb, A, which is always completely immersed in any liquid being tested. This bulb is continued in the graduated stem, B, which is much narrower in cross-section; thus, a small change in volume displacement by the hydrometer causes a relatively greater change in the length of the stem immersed. Even so, it is common to find two sizes in use, one having a range of density from 1·00 gm. per c.c. upwards and the other from 1·00 gm. per c.c. downwards.

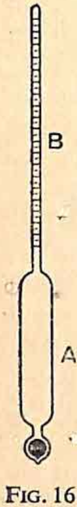

FIG. 16

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[1] As this simple form will not usually accommodate a range of 1·20 (saturated brine) to 0·82 (meths), it is recommended that more intermediate values between 1·20 and 1·00 be obtained by suitably diluting saturated brine with water.

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## The everyday importance of flotation

At this stage you think, no doubt, that this work is all very formal with little that is of any real practical value. It is not enough just to know the Principle of Archimedes; what really matters is that you should realize that it governs all practical problems in flotation. A solid block of iron sinks in water, but the same block may be retrieved, rolled into a sheet and fashioned roughly to the shape of a boat. It will then float, because by altering its shape it has been made to displace more water than it did as a solid block, enough water, in fact, to be equal in weight to the weight of the iron.

Every ship, from the ocean liner to the humble river barge, displaces, in the same way, its own weight of water, and this displacement must vary according to the load it carries. Ocean-going vessels, which have to contend with gales and high seas, must have their full loads limited so that they are not too deeply immersed in water. This immersed depth, or draught, of all ships varies in different parts of the world and at different times of the year, because the density of sea-water depends upon its temperature (see p. 50) which will depend partly on the time of the year and partly on the latitudes in which the voyage is being made. The safety levels are indicated on the hull of every ship by a series of lines, collectively known as the Plimsoll mark. (See Fig. 17.)

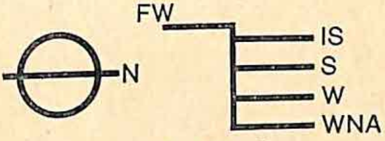

FIG. 17

N = normal loading line.
FW = loading line for fresh water.
IS = " " Indian summer.
S = " " summer in temperate zones.
W = " " winter " "
WNA = " " winter in North Atlantic.

Ocean-going steamers are not always fully or even well loaded and in rough weather the vessel may be insufficiently immersed for safe travelling. In these circumstances, spaces in the ships, known as ballast tanks, are filled with water to increase the total weight of the ship, and, thereby, the draught of the ship. If space permitted, the vessel could be so loaded to exceed the maximum displacement and perhaps eventually sink. This is what actually happens in the normal operations of a submarine. When this

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craft has to dive, valves are opened and the ballast tanks flooded with water; when it has to rise again to the surface, pumps empty the tanks and force the water through valves into the surrounding sea.

These processes of mechanical sinking and floating have been fully developed in the use of the floating dock (Plate I A). This is provided with ballast tanks, which are already partly filled with water when the dock is floating unoccupied. By regulating the inflow of water into the tanks, the dock is sunk to the required depth so that the vessel may glide into it. Water is then pumped from the tanks, and the dock slowly rises, carrying the ship, carefully propped in position, until the floor of the pontoon is above the water line. As the weight of the floating dock has been increased by the weight of the ship it carries, and as the Principle of Archimedes still applies, it will be evident that the water pumped out considerably exceeds that introduced into the tanks during the sinking operation.

# CHAPTER 3

## FIRE, HEAT AND EXPANSION

### Fire—once a god, now a servant

Man's superiority over all other living creatures is so clearly defined that, often, one is tempted to take it for granted without enquiring at all deeply as to the methods by which he obtained this mastery. It has been estimated that man began to use speech, to think and to reason about 100,000 years ago. At first he was little better than the beasts of the earth, but he has gradually developed, and his progress is in no small measure due to his mastery of fire. So great is the power of fire that, amongst some of the older races, it was feared and worshipped, but the gradual advance of human intelligence has enabled man to overcome his fear, and his reverence for the Fire God has declined accordingly. This change probably dates from the time when primitive man discovered how to make his own fire, by rapidly rotating a hard, dry, pointed stick in a hole in a piece of soft, dry wood (Fig. 18).

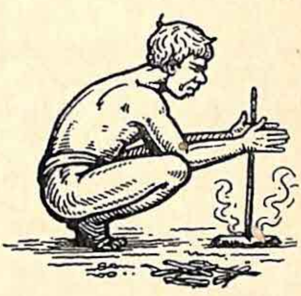


FIG. 18

Briefly stated, fire has become the servant and is no longer the master of man. The great service of fire lies in its heat-giving property—we need it to cook our food, to smelt the ores from which we get our metals, to produce the steam to drive our locomotives and factory machinery, and alas! for our own personal comfort during many months of the year. But, it should be noted, if man has obtained a mastery over fire, he is not yet able to control the heat available from a fire. A great deal of the heat derived from coal burning in the grate at home passes up the chimney, and of the heat produced in the fire-box of a high-speed locomotive more than nine-tenths is wasted.

But heat developed by fire, even the sun's fire, may not always be an obedient servant. Our first study of the science of heat is directed to some effects which it may produce, so that when the effect might be disastrous we may learn to control or avoid it. Then we may be able to use it profitably, for it is this profitable use of the effects of heat which has contributed so largely to our present requirements and personal convenience.

### Heat and temperature

When heat is supplied by a fire, the substance which receives the heat usually (but not always, see p. 178) becomes hotter; but because one object is hotter than another, it does not follow that the hotter one received more heat than the cooler one. At the outset, you must get quite clear the distinction between an amount of heat which may be supplied and the degree of hotness which it produces in the body receiving it. The term **temperature** is used to indicate the hotness of a body, and temperatures are described in a general way as high or low according as the body is hot or cold. When heat is supplied to a body, its temperature usually rises, if heat is taken from the body its temperature usually falls. (*The difference between heat and temperature will be further explained, when you have learned how to measure heat.* See p. 177.)

### An effect produced by raising and lowering the temperature of a solid body

Accompanying the rise in temperature of a body there is a further change which is, however, not so easily detected. In the case of some metals, it may be shown by the following experiments, A and B.

*Expt. A.*—One end of a long bar of iron is fixed firmly on a block of wood by means of a heavy weight. The other end rests on a knitting needle, which carries a light pointer (Fig. 19), and

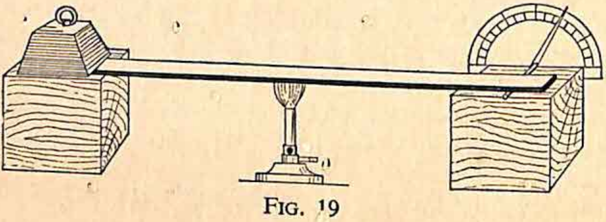


FIG. 19

can roll on a flat surface, just rough enough to prevent it from slipping.

The bar is then heated by one or more Bunsen flames and the pointer moves round like the hand of a clock. This is the only observation possible; but a careful examination as to the cause of this movement shows that since one end of the bar was kept fixed, the other end must have moved away from the fixed end. The bar has increased in length. If the heat supply is removed the pointer recovers its original position, and from this observation it is clear that the cooling solid contracts.

*Expt. B.*—The apparatus (Fig. 20) consists of a brass ball and ring, the former of such size that it **just passes** through the ring, when both are at the same temperature. After the ball is heated separately in the Bunsen flame, it rests upon the cold ring. Why? After a minute or two, the ball, while still quite hot, slips through the ring. Can you explain this second observation?

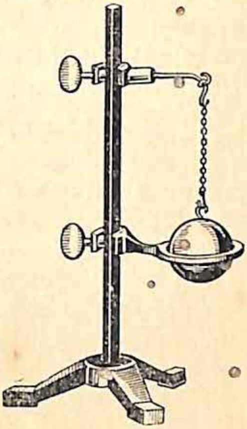


FIG. 20

## Cautionary tale

As a general rule, we may say that solids expand with rise in temperature, and contract as the result of a fall in temperature. If no allowance is made for these changes in length, area or volume, you will understand that serious consequences may arise.

*Expt. C.*—The apparatus (Fig. 21) consists of a strong iron framework with a slot at each end. These slots support a cast-iron bar with a hole at one end for carrying a short iron plug; at the other end the bar terminates in a screw thread on which a large nut can be screwed tightly, so that it and the plug make firm contact with the outside of the framework.

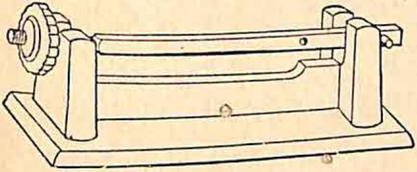


FIG. 21

The bar is heated with a blowpipe flame and the nut screwed up as tightly as possible. When the flame is removed, the bar cools but **is prevented from contracting** and in a few minutes the plug is broken. The cooling of the imprisoned bar produces forces within itself which are great enough to cause this damage.

## Do equal lengths of all solids, subject to the same changes of temperature, expand to the same extent?

*Expt. D.*—A compound bar, made by securely riveting strips of iron and brass, is quite straight at ordinary temperatures. If it is supported on a tripod and heated by a Bunsen flame, it bends (Fig. 22).

Considerable force is necessary to change its shape.

Why has this force been brought into action?

Which strip is now the longer?

When the flame is removed the complete bar recovers its normal shape. Why?

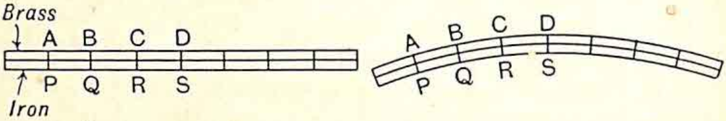


FIG. 22

## Summary of the conclusions of these experiments

**(1) Solids expand when heated and contract when cooled.**

**(2) For the same temperature change equal lengths of different solids expand or contract to different extents, e.g. brass more than iron.**

**(3) Considerable forces are brought into action when proper provision is not made for expansion or contraction which may take place.**

## Do liquids and gases expand when heated?

In planning experiments to answer this question, you must remember that liquids and gases require containing vessels and that, generally, these vessels must receive heat before the contained fluid. When experimenting with liquids, a very small quantity of dye is added to them, in order to see better all that occurs.

*Expt. E.*—A flask is filled with dyed water, and a cork carrying a long tube closes the flask so that there is no air in it and a little of the liquid is forced up the tube (Fig. 23). The flask is then plunged into a bath of hot water and the level of liquid in the tube carefully watched. First, it falls slightly but suddenly, then rises steadily past its original position and may even overflow if left long enough. Clearly, liquids expand on being heated. Can you explain why the liquid first descended in the tube?

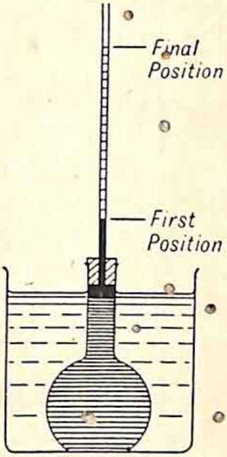


FIG. 23

When the liquid began to expand it rose far beyond its original level. Does this tell you anything about the expansion of water compared with the expansion of the solid vessel containing it?

If the liquid assumes a final position as shown, the flask may then be removed and plunged into a bath of cold water. In this case, the level first rises and then falls. Can you explain these movements?

To answer the question for gases, only a slight modification of the above process is necessary.

*Expt. F.*—A flask is closed with a cork carrying a long tube, and this is mounted, as shown (Fig. 24), with the open end of the tube immersed in some dyed water in a beaker. When the warm hands are placed upon the flask, bubbles escape through the dyed water. How do you explain this escape? When the hands are removed, the dyed water rises in the tube. Why?

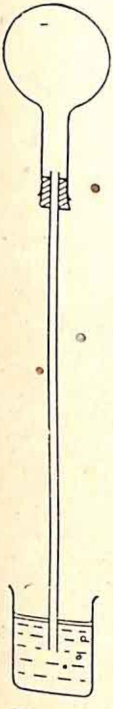


FIG. 24

It is important to note that these effects have required neither a Bunsen flame, nor even hot water: the heat supplied by the hands has been sufficient. We may emphasize this by soaking a rag in hot water, laying it on the flask, and removing it when the escape of bubbles has ceased. What do the last observations show regarding the expansion of gases?

## Do equal volumes of all liquids expand equally for the same changes of temperature?

*Expt. G.*—This follows the method of Expt. E, but, to reduce the bulk of apparatus, boiling tubes (Fig. 25) are used instead of flasks. Each must hold the same volume of liquid and be fitted with a tube of the same bore. Suitable liquids are: A, water dyed with red ink; B, alcohol dyed with a shaving of copying-ink pencil; C, chloroform dyed with a flake of iodine; D, mercury. The levels of these in their respective tubes should be as nearly as possible the same. The tubes are then mounted in a bath of warm water and the separate changes in height, when steady, of the liquids noted. Which liquid has expanded most; which least? Now write down in order the list for all the liquids observed, to show their relative expansion when examined under exactly similar conditions.

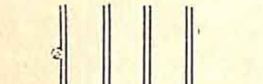


FIG. 25

## Expansion of gases

You are probably anticipating a similar question concerning the expansion of different gases, examined under exactly the same conditions. Gases expand so readily that it would suffice to use tepid water as the heating source to raise them to the same temperature. Apart from the difficulty of adjusting their starting volumes to be equal, it must be recalled that gases are easily compressible; therefore, it is equally important to be sure that they are kept under the same conditions of pressure (see Chapter 14) during the test.

This last condition needs an experiment much beyond the present standard of your work, but the information derived from such an experiment should be known so that it may be added to the corresponding facts which have been observed for solids and liquids. Moreover, having anticipated the question, you will probably be surprised by the answer. Under exactly the same conditions (volume, pressure and change of temperature) all gases expand to the same extent.

**Summary of information for expansion of liquids and gases.**

**(1) Liquids expand when heated and contract when cooled.**

**(2) For the same temperature change equal volumes of different liquids expand or contract to different extents, e.g. alcohol more than water, water more than mercury, and chloroform more than alcohol.**

**(3) Gases expand very readily when heated and contract just as readily when cooled.**

**(4) For the same experimental conditions, all gases expand or contract to the same extent.**

## CHAPTER 4

# THERMOMETERS AND TEMPERATURE MEASUREMENT

During the experiments to prove the existence of expansion and contraction, it was sufficient to realize that the temperature of the body had been raised or lowered. You must now consider how this knowledge of expansion may be used to state more precisely by how much the temperature has been raised or lowered, or to record at any particular time just how hot a substance is. For most purposes, the expanding and contracting substance used is a liquid and the instrument which records the temperature is a **thermometer.**

### The common thermometer

If you compare (Fig. 26) an ordinary thermometer with the original apparatus used for showing expansion of liquids you will note some points of similarity. The flask containing most of the liquid corresponds to the **bulb** of the thermometer, and the tube used to indicate the expansion to the **stem** of the thermometer. Because the bulb is very much smaller than the flask, so the **bore** of the stem must be much narrower than that of the tube.

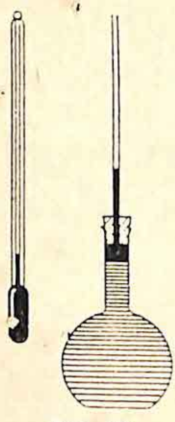


FIG. 26

Although the original apparatus might occasionally be used as a temperature gauge, its size, shape and unwieldy character are opposed to general use, especially in the many instances when a change of temperature must be recorded as quickly as possible. Further, as you will learn later, water is not a good choice of liquid to put in a thermometer.

Continuing your comparison, you should specially note that the thermometer has on its stem a series of graduations, because you want your temperature gauge to do a little more than indicate very hot, hot, cold, etc. You want it, as far as possible, to indicate by means of a numbered scale just how hot its surroundings are. How is this to be done? Nothing in your previous experience of measurement will help you here: you need a standard range of temperature. Further, this range must be sub-divided and each division given an appropriate number to identify it.

The **actual** and **invariable standards** of temperature which fix this range are:

(1) The temperature at which ice melts.
(2) The temperature of steam issuing from boiling water, when the pressure of the air is 76 cm. of mercury (see p. 128).

These standards are known as the **fixed points,** and they are indicated by the level of the mercury in the stem of the thermometer when **its bulb and that part of the stem containing mercury** are:

(1) immersed in melting ice (Fig. 28);
(2) immersed in steam from water boiling in a hypsometer (Fig. 29), the air pressure being 76 cm. of mercury.

These levels are carefully marked and the distance between them divided into a number of equal parts according to the numbered scale to be adopted.

## The common scales of temperature

The two scales in common use are (*a*) the **Centigrade** scale, and (*b*) the **Fahrenheit** scale. On the Centigrade scale, the lower fixed point, called the freezing-point, is distinguished by the number 0 and is called 0° C.; the upper fixed point, the boiling-point, distinguished by the number 100, is called 100° C. The distance between these two marks is divided into 100 equal divisions (or steps; *centum*=100, *gradus*=step) called degrees.

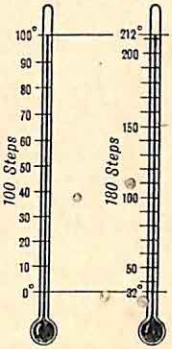


FIG. 27

On the Fahrenheit scale, the lower fixed point is 32° F., the upper fixed point 212° F., and the distance between them is divided into 180 degrees. Thus a range of 100 Centigrade degrees is the same as one of 180 Fahrenheit degrees.

Two thermometers, one of each type, placed in the same water-bath will acquire the same temperature. If the thermometers are identical in design and size, the mercury in each will rise to the same height in each stem: only the numerical system of recording and stating this same temperature on each will differ. This may be emphasized by the following list of some common temperatures, recorded by each thermometer:

| | Centigrade reading | Fahrenheit reading |
|---|---|---|
| Healthy body (average) . . | 36·9° C. | 98·4° F. |
| Summer day . . . . | 25° C. | 77° F. |
| Comfortable room . . . | 15° C. | 59° F. |
| "Hot" bath . . . . | 45°–50° C. | 113°–122° F. |

EXPT. 1.—*To check the fixed points of the thermometers provided.*

(*a*) Apparatus: Glass funnel, stand with ring to support funnel, thermometers, 2 beakers, one containing small pieces of clean ice.

The funnel is mounted in the ring (Fig. 28) and the thermometer clamped so that its bulb is near but not at the bottom of the funnel. The empty beaker is placed under the funnel and sufficient ice placed in the funnel to surround the bulb and the stem up to the lower fixed point of the thermometer under test. The mercury level is watched and when steady its position is noted and recorded.

(*b*) Apparatus: Tripod, gauze and Bunsen burner, hypsometer, pure water, thermometers, cork to fit hypsometer.

The simplest form of hypsometer, shown in the diagram, consists of a flask and a conical metal hood with a cylindrical pipe in it. Holes near the top of the pipe and at the side of the cone are provided as exits for the steam. The cork must be correctly bored to take the thermometer.

The apparatus is assembled as shown in Fig. 29, the thermometer being pushed through the cork so that the bulb does not touch the water and the upper fixed point to be tested shows just above the cork. The water is boiled steadily and the mercury level noted when it is stationary. The pressure of the atmosphere should be known (refer to p. 128). If it is not exactly 76 cm. of mercury, you should allow 0·5° C. above or below 100° C., the true fixed point, for every 1·5 cm. which the barometer reads above or below the normal value of 76 cm., before deciding whether your thermometer is correctly marked. For a Fahrenheit thermometer, the allowance is 1° F. for every 1·6 cm. difference from 76 cm.

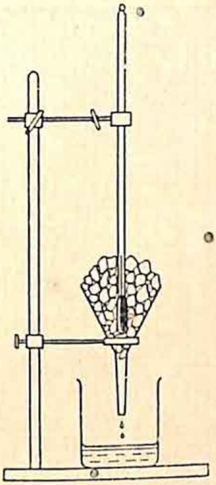


FIG. 28

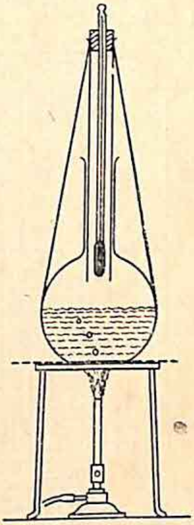


FIG. 29

## Interchange of C. and F. thermometer readings

If you have recorded a particular temperature on the Centigrade scale, it may be necessary to know what a Fahrenheit thermometer would read at the same temperature. This can be done by comparing the readings on these thermometers when they are at the same temperature, a number of corresponding readings being taken at various temperatures between the fixed points. A chart, or graph, is then prepared from which any required conversion can be read off at once.

EXPT. 2.—*To construct a graph of corresponding readings on Centigrade and Fahrenheit thermometers.*

Apparatus: Tripod, gauze, Bunsen burner, beaker, thermometers, squared (or graph) paper, can of cold water.

Heat some water in the beaker nearly to boiling-point, then remove the flame. Stir well and read the temperature of this water recorded by both thermometers at the same time.

Cool the water slightly by adding a little cold water; stir well and read the temperature on both thermometers as before.

Repeat this process, cooling the water in stages until about ten pairs of readings have been obtained, and record your values in a table as shown (Fig. 30). Plot the points for corresponding readings on the graph paper, preferably Centigrade readings horizontally, Fahrenheit readings vertically.

| °C | °F |
|---|---|
| 95° | 203° |
| 87° | |
| etc. | |

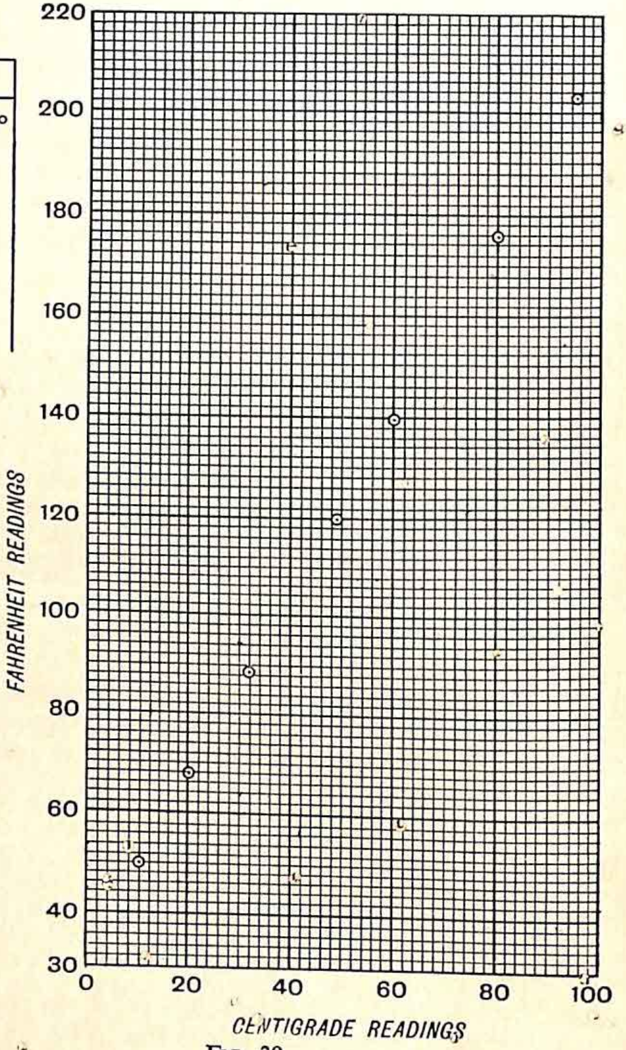


FIG. 30

What other points could you safely plot besides those obtained from your experiment? What do you notice about the points plotted? How will you use this chart to convert C. to F., or F. to C. values?

**Alternative method**

Instead of the graphical method of conversion, based on the last experiment, the process can be effected by simple arithmetical calculation. The following examples show how this is done. Before dealing with these, you should recall that the conditions for both thermometers must be the same. You are merely concerned with expressing the same thing (a degree of hotness) by two different numbers, just as you might on another occasion express the length of a particular field in yards or metres.

*Problem* 1. *What temperature on the F. scale is the same as* 40° *C.?*

The corresponding readings on both thermometers are known for the two fixed points (Fig. 31). To record a temperature of 40° C., the mercury level would have to move $\frac{40}{100}(=\frac{2}{5})$ of the standard range upwards from its lower fixed point. To record this temperature on the F. scale, the mercury level must travel over precisely the same fraction, i.e. $\frac{2}{5}$ of its standard range also upwards from its lower fixed point. But the standard range on the F. scale is 180 divisions.

∴ The mercury level must move upwards $\frac{2}{5}$ of 180 divisions from its lower fixed point, i.e. 72 divisions above the mark 32.

∴ The F. thermometer records the temperature as 104° *F.*

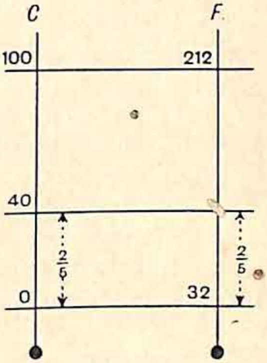


FIG. 31

*Problem* 2. *During a very cold night a F. thermometer showed the temperature to be* 14° F. *What would be the Centigrade reading for the same conditions?*

The mercury has moved 18 divisions, i.e. $\frac{18}{180}$ or $\frac{1}{10}$ of the standard range downwards from its lower fixed point on the F. scale. Hence on the C. thermometer it moves $\frac{1}{10}$ of the standard range downwards from the lower fixed point.

$\frac{1}{10}$ of the C. standard range is 10 divisions.

∴ On the C. thermometer the mercury level moves down 10 divisions from the mark 0 and reads 10 degrees below zero, i.e. −10° C.

## The choice of a thermometric liquid

The liquids commonly used in thermometers are mercury and alcohol. One of the first requirements of a serviceable thermometric liquid is that it should remain liquid over a large range of temperature.

Mercury freezes at −39° C. and boils at 357° C.
Alcohol freezes at −112° C. and boils at 78° C.

These figures show why alcohol thermometers are more generally used in Arctic regions. In the account of his attempts to reach the North Pole in 1893–5, Fridtjof Nansen records that the cold was so intense that the mercury of the thermometers remained frozen for several days (*Voyage of the Fram*). But for most purposes in temperate climates mercury possesses many advantages over alcohol. These are:

(1) It does not wet and stick to glass.
(2) It is a good conductor of heat (see p. 193), and is therefore quickly heated or cooled throughout its bulk.
(3) It does not require much heat from its surroundings to raise its temperature, or release much to them when its temperature falls (see p. 175).
(4) Its opacity renders it easily visible even as a very thin thread in the stem of the thermometer.

## Thermometers for special purposes

Among the daily weather records are the highest and lowest temperatures of the air for every period of 24 hours. By means of specially designed thermometers, the actual maximum or minimum temperature can be read some hours after it was recorded. Such thermometers are sometimes called self-registering thermometers.

**The maximum thermometer** (Fig. 32) is merely an ordinary mercury thermometer with the stem bent just above the bulb.

The process of bending the stem causes a constriction in the bore and although the expanding mercury is forced forward through this constriction, it will not return from the **horizontal** part of the stem to the bulb when the temperature falls. The reading of the thread at A therefore gives the maximum temperature for the period. The instrument is re-set for the next period by jerking the mercury past the constriction into the bulb. In the older forms of this thermometer, a glass or steel indicator was pushed forward by the meniscus of the expanding mercury. With the stem bent as shown, this indicator is not necessary.

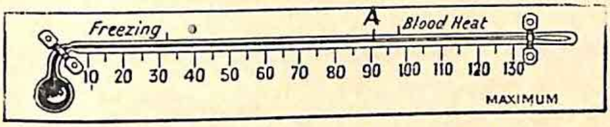


FIG. 32.—A maximum thermometer[1]

**The minimum thermometer** (Fig. 33) contains **alcohol,** and inside the liquid in the stem is a glass or steel indicator. Like the maximum thermometer, this instrument is used with the stem horizontal. As the temperature falls, the alcohol meniscus travels towards the bulb, and as soon as it makes contact with the indicator it draws this along towards the bulb with it. Whenever the temperature rises, the meniscus moves away from the bulb, but it leaves the indicator behind to record the lowest temperature of the period. This instrument is re-set by tilting it so that the indicator slides along in the alcohol, until it touches the meniscus.

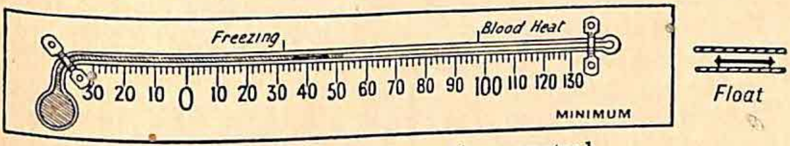


FIG. 33.—A minimum thermometer[1]

**The clinical** (or doctor's) **thermometer** (Fig. 34) is really only a "pocket edition" of the **maximum** thermometer. There is the

[1] These thermometers, as usually supplied, use the term "Blood Heat". This should be Blood Temperature (see pp. 32, 177 and 183).

constriction of the bore just above the bulb, but the stem is straight and quite short, because the use of the instrument is limited normally to recording temperatures which lie between 95° F. and 110° F.

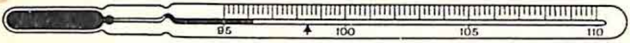


FIG. 34.—A clinical thermometer

With small variations of the temperature of a sick person, fractions of a degree become of great importance and the scale therefore shows a range of fifteen Fahrenheit degrees, each of which is further divided into fifths.

## CHAPTER 5

# EXPANSION AND CONTRACTION IN DAILY LIFE

The various facts which you have learned from the experiments on expansion are of great importance in our lives. Sometimes the knowledge is used to advantage. Already, in the use of the thermometer, temperature changes have been recorded by means of the expansion or contraction of a liquid. But it is necessary to realize that danger may often arise from the considerable forces which may be developed and that, accordingly, suitable allowances must be made to avoid possible disaster.

### Some simple cases

The applications of the results of our expansion experiments are so numerous that only a selection of them can be considered here. Allowance for expansion is provided in the loosely fitting bars of a gas cooker, and in the panes of glass which do not fit exactly into their picture or window frames. Allowance for contraction must be made when telegraph wires are hung in summer.

The forces at work in contraction are employed by the wheelwright, who selects an iron rim, which, when cold, is just too small for the wheel which it is to cover, and when hot is just large enough to be slipped on. Flanges of wheels used on railroads are also fitted in this manner if the wheels have spokes, e.g. the driving wheels of a locomotive. But if the wheels are solid, e.g. those of a passenger coach, the process is reversed; the wheel is shrunk by cooling and the flange then slipped on. In either case, the result is the same—a tight grip between flange and wheel when both have acquired the same temperature. In spite of recent advances in the methods of welding metals, the steel plates of many boilers and ships are still securely fastened together by using hot rivets (Fig. 35) which are inserted and hammered down to grip the plates before the rivets themselves have cooled very much.

Observant country walkers will have noticed the X and S iron signs attached to the walls of old barns, and should have little difficulty in supplying the reason for them.

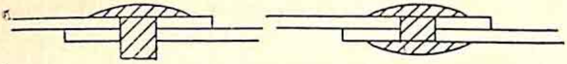


FIG. 35

If the pendulum of a clock expands and contracts with the daily rise and fall in temperature, it will not swing at a constant rate and the clock will not keep good time. This fault is now corrected by making the pendulum rod of **invar.** For all practical purposes, this alloy of steel and nickel (36 per cent) suffers no change in length with atmospheric changes of temperature.

## Simple applications of bimetallic strips

A compound strip made by riveting or electrically welding together two strips of different metals is called a **bimetallic strip** (*bi*=two). If it is straight at room temperature, a rise in temperature causes it to curve so that the metal which expands more is on the outside of the curve. A fall in temperature would cause it to curve in the opposite direction. A strip which is curved initially changes its curvature with a change of temperature.

*Does your watch keep good time?*

The timing of a watch depends upon the following conditions:

(1) The strength of the hair spring.
(2) The radius of the oscillating balance wheel.

A rise in temperature weakens the spring and increases the radius of the wheel, for both of which reasons the watch would register too slowly. Both errors are corrected by constructing a balance wheel (Fig. 36) with a bimetallic, broken rim of steel and brass, so that as the spokes expand outwards, each section of the rim curves inwards. By referring to the compound bar experiment in which these metals were used (p. 26), you should be able to decide which metal is on the outside of the rim. It is important to notice

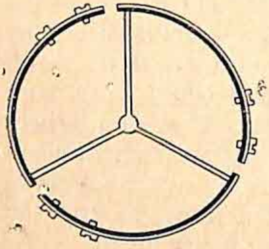


FIG. 36

that the change in curvature compensates for the weakening of the spring, as well as for the expansion of the spokes. (An invar balance wheel would keep the radius of the spokes constant but the change in the strength of the spring would still persist; the use of invar would not eliminate the trouble of false timing of a watch as it does in that of a clock.)

*Automatic temperature control.*

Fig. 37 shows how a bimetallic strip can be used to switch on an electric current. B is the strip; $T_1$ and $T_2$ are the terminals by which the instrument is joined into an electric circuit. If the strip is straight, so that it does not touch the adjustable screw S, the current does not flow. If the temperature rises, the strip curves (as shown by the dotted lines) and touches the screw. This contact completes the electrical circuit and a current flows. Such a switch is sometimes used in a furnace chimney. If the temperature becomes too high, a current is switched on and a warning given (e.g. by ringing a bell). A similar device can be used as a fire alarm. You should now try to design a switch to *turn off* a current when the temperature rises above a certain value.

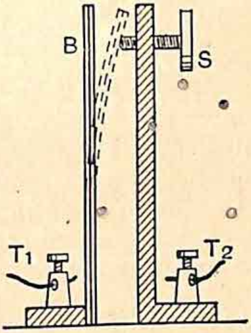


FIG. 37

A **thermostat** is a device which, working automatically, maintains a constant temperature, sometimes in a vessel of water in the laboratory, sometimes in an oven at home, and even in the large rooms of public buildings. A bimetallic strip is often used to control a thermostat. The switching on (or off) of a current can be made to operate the instrument which provides the heat.

## The thermograph

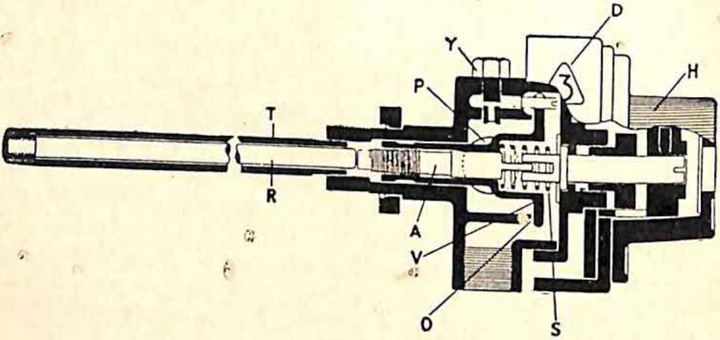
In Chapter 4 (p. 37) we examined the working of the self-registering thermometers. In addition to knowing the maximum and minimum temperatures of a given period of 24 hours, it is often desirable to know how the temperature was changing at any time during that period. This knowledge is furnished by a thermograph (Plate IB) which may be set once per week and left to record continuously for the ensuing seven days.

The thermometer consists of a bimetallic strip made of brass and invar. The strip is coiled in the form of a spiral; the invar being on the outside and the brass on the inside of the coil. The coil is mounted on a horizontal axis at the end of, and just outside, the case which encloses the recording apparatus. One end of the coil is connected through the horizontal axis to the arm which carries the pen, and the other is fixed to the case, through a fine adjustment screw. By means of this screw, the coil can be adjusted so that the pen may be set to make its mark at the temperature which agrees with that given by a standard thermometer.

When the temperature rises, the end of the coil carrying the pen arm causes the latter to move upwards, and when the temperature falls, the arm moves downwards. Corresponding movements are therefore transmitted to the pen itself which draws its line of varying temperature upon the chart mounted on the drum. This chart is printed to show, by horizontal lines, the temperatures in degrees Fahrenheit. For easy reference, each day is divided into periods of two hours by slightly curved lines drawn from the top to the bottom.

## The "Regulo" control of a gas oven

The "Regulo", which is fitted to most modern gas ovens, is another example of thermostatic control. Fig. 38 shows a section of this device. Coal-gas from the main is led into a chamber by a pipe P, the end only of which is shown here. The chamber is



[Reproduced by permission of Radiation, Ltd.

FIG. 38.—Diagram of "Regulo".

covered by a valve V and the gas reaches the burners through the opening O. The size of this opening controls the supply of gas to the burners and hence the temperature of the oven. It is required that the size of the opening will change automatically whenever the temperature of the oven rises above or falls below the desired temperature.

To "set" the oven, the dial D is turned until the appropriate figure (or letter) is seen. This rotation of the dial turns the spindle A which screws inside the valve head V. The turning of the spindle thus moves the valve head and so adjusts the opening to the correct size. The far end of the spindle is kept permanently in contact with the invar rod R by means of the spring S. The lower end of this rod is fixed to the closed end of the surrounding brass tube T (called the expanding tube).

When the temperature of the oven rises, the brass tube expands and pulls the non-expanding invar rod with it. As the spring keeps the spindle, with its meshed valve head, in contact with this rod, the opening O is made smaller. The supply of gas is therefore reduced. Conversely, if the temperature falls, the opening becomes bigger. (Y is a by-pass which allows a small flow of gas always to reach the burners. Without this, the burners would go out if the valve completely closed the opening.)

## Expansion joints

Most large buildings are warmed by the process of central heating (p. 198), which involves conveying hot water in long iron pipes from a boiler house to various parts of the building. In factories it is often necessary to convey steam by means of iron pipes. For constructional reasons, the whole length of the pipe must be made in sections and the joins of these must be watertight. These pipes are not always hot; they expand and contract, and allowance must be made for this. One

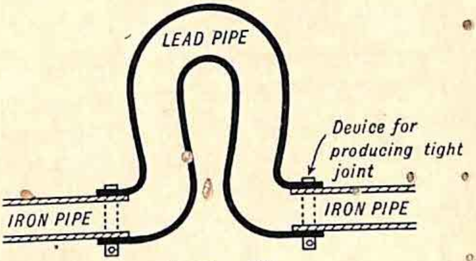


FIG. 39

method of dealing with this effect is to unite the straight sections of piping by curved pipes, made of softer metal, usually lead (Fig. 39), so that as the straight sections expand and contract, they force or draw the curved pipe slightly out of shape. This change is quite small and usually cannot be detected by the eye; the soft metal yields easily and no force is exerted within the metal.

The alternative method is illustrated in the accompanying diagram (Fig. 40). The ends of two consecutive pipe lengths are arranged to be a small distance apart and this break is covered by a short tube, called the collar. This is sufficient to allow for expansion and contraction because the two ends inside the collar can move together or apart. Even when the collar fits tightly the force available from the expansion or contraction enables the pipes to slide within the overlapping collar. As the collar may not be a perfect fit, and therefore not absolutely watertight, a thick rubber ring is mounted on each side of it, each pair of rings being kept in position by bolted iron covers which can slip along the pipe just as the pipe itself slips inside the collar.

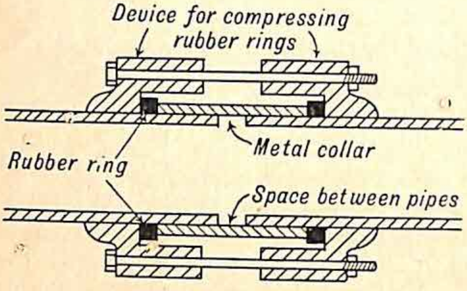


FIG. 40

## Safety on railways

The lines of a railroad are exposed to the heat waves of summer and occasional Arctic temperatures of winter. It is therefore necessary to allow for their expansion. But if these rails are to carry heavy trains running at high speed, they must be securely bolted together. The need for the space between consecutive lengths of rail is readily understood. It is not so easy to see how expansion into this space may take place, when the connecting fish-plates are securely bolted to each rail (Fig. 41), because the fish-plates will themselves expand away from the space. The bolt holes in the plates are oval, whereas those in the rails are circular. Provided the rails are firmly secured to the sleepers, sufficient force is produced by the expanding or contracting rails and plates to make them slide over each other in opposite directions.

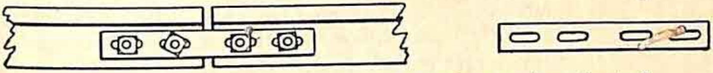


FIG. 41.—Showing oval holes in fish-plate and method of connecting rails

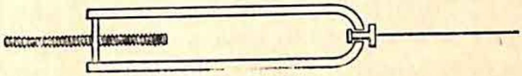


FIG. 42

But safety on railways involves more than a securely laid line. Points and signals must operate properly on all occasions, and as these are worked, often at a distance, by iron rods and wires, proper provision is necessary for counteracting trouble arising from changes of length. There is no compensating device for dealing with signal wires; they have to be attended to as occasion demands. Between the lever in the cabin and the wire running by the side of the track is a wire strainer, a frame with a long screw threaded through one end. The frame is rotated, drawing in or releasing the screw until the correct slackness in the wire is obtained (Fig. 42).

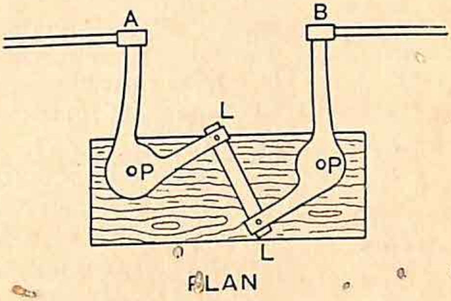


FIG. 43

The method of compensating the rods for expansion and contraction is illustrated in the diagram (Fig. 43). The two arms which are connected to the rods at A and B turn round fixed pivots P mounted in a baseboard embedded in the ground; the short cross arm is connected to the side arms by means of loose swivel pins LL.

Finally, a railway must often be carried over a road or a river. Where this is done by means of a steel bridge it is most important that provision for the changing length of the bridge should be made. A notable instance occurs in the case of the Forth Bridge; the overall length of its three girders is nearly 5000 ft. (Fig. 44). The only fixed parts of the bridge are those, marked F, mounted on the piers. The ends marked B of the system of girders are mounted on roller bearings shown in detail in the diagram (Fig. 45), and in two portions, marked R, the girders are supported on the cantilevers (under arches) by means of rocking posts (Fig. 46). These posts, as their name implies, can move so that they are not necessarily vertical. This movement and the end compensation on the roller bearings allow the whole structure to expand and contract without being damaged by suffering undue strain.

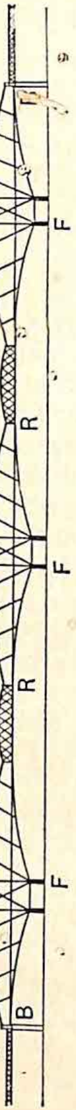


FIG. 44.—Forth Bridge (diagrammatic).

### Exact knowledge

So far, our experiments have only proved the existence of expansion and contraction, and the exertion of great forces whilst this expansion or contraction takes place. We know, also, that under the same conditions different substances expand to different extents. The knowledge of these facts enables us to appreciate why corrections and allowances must be made. If we are to understand how these corrections are accurately made, we must have more information. For example, we must know what length to allow between consecutive rails on a railway. To be able to calculate this length, we must know by how much a certain length of steel expands (or contracts) when subject to a particular rise (or fall) in temperature.

This numerical information is given by a value called the coefficient of linear expansion, which is defined as follows:—

**The coefficient of linear expansion is the increase in length of unit length of a substance for a rise in temperature of one degree.**

*Example.*—If a Centigrade thermometer is used to record the temperature, the coefficient of linear expansion of steel is 0·000012. Therefore, if unit length (e.g. 1 ft.) is warmed so that its temperature rises 1° C., its length increases by 0·000012 unit (e.g. ft.).

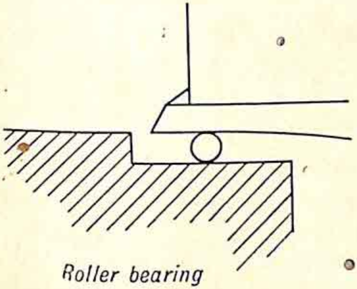


FIG. 45

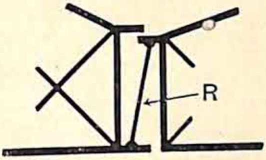


FIG. 46

To use this information for any other steel rod of known length, subject to any known rise of temperature, you must also note that **the actual expansion is proportional to**

(1) **the length of the rod used,** and
(2) **the rise in temperature to which it is subject.**

*Problem.—By how much will a steel rail* 60 *ft. long expand if its temperature is raised* 10° C.?

Using the coefficient already stated, we have:

1 ft. for a rise of 1° C. expands by 0·000012 ft.
∴ 60 ft. ,, ,, 1° C. expand by 0·000012 × 60 ft.,
and 60 ft. for a rise of 10° C. expand by
0·000012 × 60 × 10 ft., i.e. by 0·0072 ft.

Now refer back to the definition and note that we say unit length and not 1 cm. or 1 ft., because it is clear that if

1 cm. for 1° C. rise expands by 0·000012 cm., then
1 metre for 1° C. ,, ,, 0·000012 metre, and
1 mile for 1° C. ,, ,, 0·000012 mile and so on.

Further, although the definition states a rise in temperature of one degree, you should note that this need not be 1° C.; it may be 1° F. In fact, nearly all English engineers use the Fahrenheit scale in their work in which they are concerned with temperatures. But you must remember that a rise of 1° F. is less than that of

1° C. Therefore, if you change over to the Fahrenheit scale, the value of the coefficient cannot be the same. Thus, for steel the coefficient when using the Fahrenheit scale is 0·0000067. How has this value been obtained?

The following table gives the coefficients of linear expansion of some of the commoner substances and of a few alloys of special importance:

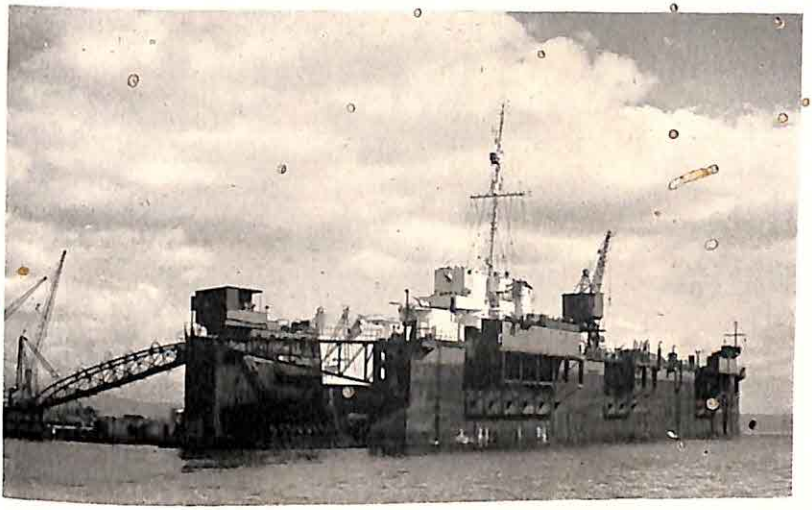
| Substance | Coefficient per 1° C. | Coefficient per 1° F. |
|---|---|---|
| Zinc | 0·000026 | 0·0000145 |
| Aluminium | 0·0000255 | 0·0000142 |
| Brass | 0 000019 | 0·0000105 |
| Copper | 0·000017 | 0·0000094 |
| Steel | 0·000012 | 0·0000067 |
| Glass | 0·0000089 | 0·0000049 |
| Platinum | 0·0000089 | 0·0000049 |
| Portland stone | 0·000003 | 0·0000017 |
| Nickel-steel alloy (45 per cent nickel) | 0·0000089 | 0·0000049 |
| Invar | 0·0000009 | 0·0000005 |

## The value of nickel-steel alloys

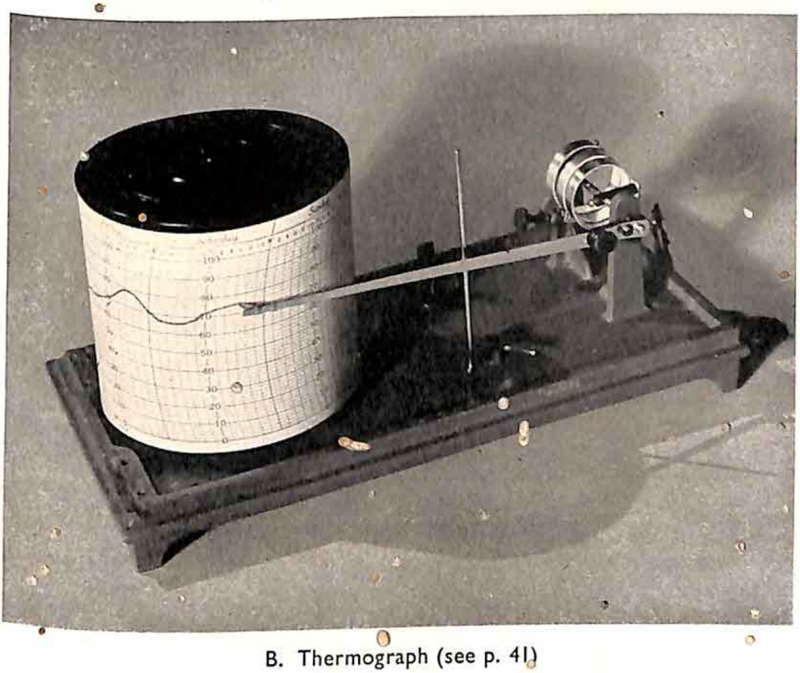
It has already been stated (p. 40) that for all practical purposes invar suffers no change in length when subject to atmospheric changes of temperature. Another important alloy of nickel and steel is that quoted in the table above. It has the same coefficient as glass and platinum. It is often necessary to have joints between metal and glass, which shall be gas-tight and not fracture or break loose when the temperature of the joint changes. Formerly these joints were made by fusing platinum into glass, but the discovery of M. Guillaume, that this particular alloy of nickel and steel has the same coefficient as platinum, has produced a substitute for a precious metal.

## The curious behaviour of water

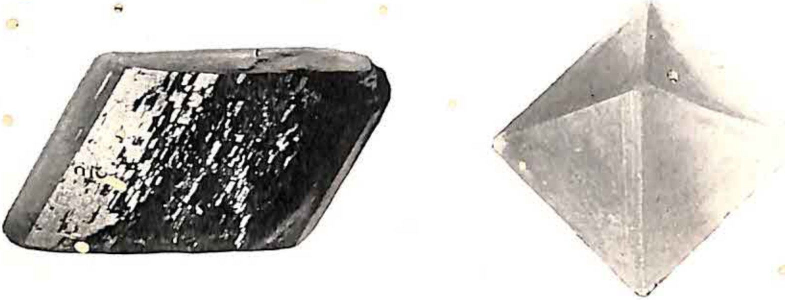
In the experiments to show the expansion and contraction of water, this liquid was heated from room temperature, probably about 15° C., and allowed to cool to this temperature. Now water exists normally as a liquid at any temperature between 0° C.



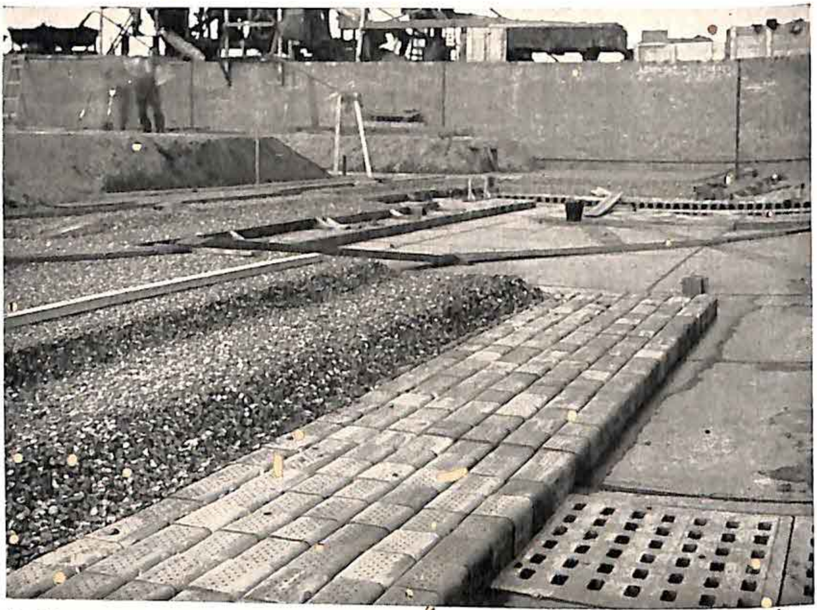
A. Frigate undergoing repairs in the floating dock at Harland and Wolff's, Belfast (see p. 22)



B. Thermograph (see p. 41)


(i) (ii)

A. Crystals of (i) copper sulphate, (ii) alum


B. Slow, sand filter-bed under construction, showing layers of shingle and sand (see p. 54)

and 100° C., and if a quantity of it is cooled from 15° C. down to 0° C. you might expect it to contract in the usual way. The following experiment will decide whether or not this is so.

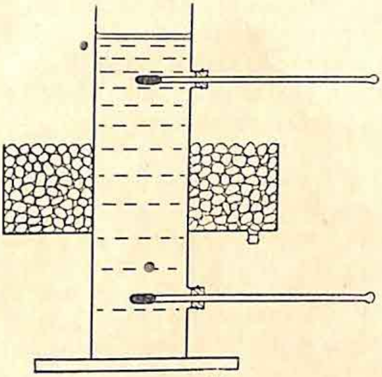


FIG. 47

*Expt. A.—To observe the behaviour of water when it is cooled from room temperature to freezing point.*

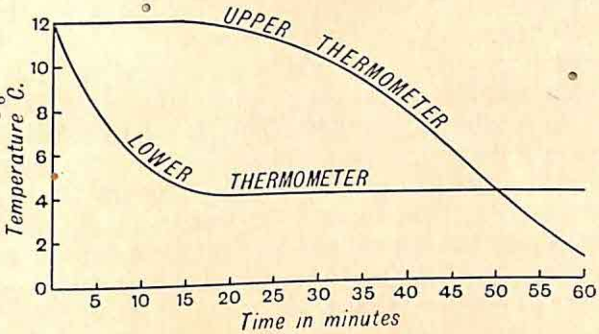


FIG. 48

The apparatus, known as Hope's apparatus, is shown in Fig. 47. Pure water fills the tall cylinder, carrying two thermometers as shown, and a freezing mixture—a mixture of ice and salt having a temperature well below 0° C.—is placed in the trough around the cylinder. Both thermometers are read every five minutes until the temperatures recorded are constant (or very nearly so). A graph is drawn (Fig. 48).

If a liquid contracts, its density increases; conversely, if its density decreases, the liquid must have expanded. Moreover, if immiscible liquids of different density are placed in the same vessel, the densest of them will settle at the bottom. The graph shows that the temperature at the bottom of the cylinder decreased steadily and then remained stationary at 4° C. It follows then that this is the temperature at which water has its greatest density. **Cooling below 4° C. decreases the density, i.e., causes the water to expand.**

## Aquatic life in winter

This exceptional result explains what takes place during the freezing of ponds and lakes in winter. Cooling takes place chiefly at the surface. Whilst the temperature is falling to 4° C., the density of the surface water is increasing, and this denser water slowly sinks to the bottom. Below 4° C., the surface water now decreases in density and remains on top, supported by the denser water below until the surface water eventually freezes. The sheet of ice thus grows downwards; further, since water conducts heat very badly (p. 192) the temperature near the bottom of the pond seldom falls below 4° C. unless it is shallow.

It is sometimes pointed out that it is this peculiar behaviour of water which enables aquatic life to survive in fairly deep ponds and lakes during the hardest of winters. It must be admitted that as things are, it does so; but, it is also known that throughout the long period in which living creatures have inhabited the earth and the waters thereof, their forms have been naturally adapted to enable life to survive according to existing conditions, and that when this very gradual change has ultimately proved impossible, the species has become extinct.

# CHAPTER 6

# HOW WE SEPARATE SUBSTANCES FROM NATURAL MIXTURES

## Introduction

We now begin the study of matter (p. 1), to find out what all the different substances we come across are made of, to find whether they are related, and, if so, exactly how. In order that we may recognize substances, we must examine their properties or qualities (p. 62). We shall learn how substances are made, and find how and with what other substances they will react to produce new substances.

The particular science to which this part of the work belongs is chemistry. The word "chemistry" is supposed to be derived from the Egyptian word *kemi*, or *chemi*, which means "the black land". The word may refer to the black soil of the country or to the fact that men who performed chemical operations had to do so secretly.

The raw materials found in nature, and from which we have to start, are usually mixtures, i.e. they consist of particles of different substances intermingled with each other. We have to isolate separate substances before we can study them, and in this chapter you will learn something of the simpler methods which are employed in separating substances from mixtures.

Expt. 1.—*What happens when solids are mixed with water?*

Take a number of solids, e.g. salt, copper sulphate, chalk, iodine and wax. Put a little of each solid, in turn, into test-tubes about half-full of water. Shake up each tube, after closing its mouth with your thumb. Note exactly what happens to each solid.

## The effect of mixing certain solids with water

When salt is shaken up with water, the solid disappears into the liquid, which remains colourless. Copper sulphate also disappears, but in this case the liquid is coloured blue and is clear. Chalk, however, gives an opaque, milky liquid; iodine does not seem to change much, but the liquid becomes very pale brown;

wax simply floats. Solids like salt and copper sulphate which disappear on shaking or stirring with a liquid are said to dissolve in the liquid. The solids are soluble in the liquid and the resulting mixture is a **solution.** Iodine is very slightly soluble in water; wax is insoluble.

When a solution is left to stand, the dissolved solid does not settle. The milky liquid obtained by shaking chalk and water gives, on standing for a short time, a white sediment; the liquid becomes clear. The fine particles of chalk were in **suspension,** not in solution. You cannot decide from this little experiment whether chalk dissolves in water; it may dissolve just a little. Powdering a solid which is soluble always helps it to dissolve quickly, because a powdered solid has a large surface.

You will find that solutions play an important part in living processes. Most of the food you eat is insoluble in water; it has to be changed into soluble substances before it can pass into the blood. Again, all the solid food which plants take up from the soil passes into the roots in dilute solution.

## Some other liquids which dissolve solids

A liquid which will dissolve substances is called a **solvent.** In addition to water, some common solvents which you should know are benzene, alcohol, turpentine, paraffin and acetone.

Wax will dissolve readily in benzene, so that this liquid can be used for removing grease-spots from clothing; other solvents, e.g. carbon tetrachloride and trichlorethylene, which are safer because they do not burn, are employed for "dry-cleaning" clothes.

Iodine, which is a blue-black, lustrous solid, easily dissolves in alcohol; the brown solution thus obtained is essentially tincture of iodine. Alcohol is the common solvent used for making perfumes; it dissolves certain oils, e.g. oil of lavender, which have powerful odours. Quick-drying stains also contain alcohol as a solvent.

Turpentine is chiefly a solvent in paint. It is also used in making various kinds of polish since it dissolves beeswax.

Acetone and amyl acetate are two liquids which dissolve celluloid. They are used in joining cinematograph film, in certain quick-drying paints, and in some adhesives, i.e. substances which stick things together, now in common use.

## How can an insoluble solid be separated from a liquid?

We can simply allow the solid to settle, then pour off the liquid. This does not give a good separation, so it is usual to filter or strain the mixture; the process is called **filtration.** If the particles of solid are large, a fine-meshed strainer will do, such as a tea-strainer, or a cloth may be used. The latter device is used in making clear fruit-jellies. In the laboratory we use thin sheets of absorbent paper which we call filter-paper.

EXPT. 2.—*Filtration in the laboratory.*

Fold a filter-paper across a diameter, then into quadrants (see Fig. 49). Next, form a cone with the paper, opening the quadrants as shown. Fit the cone into a funnel, wetting the paper while you hold it down; it will then remain in position. Now, make a solution of red ink in water in a test-tube. Pour the solution into the paper, but not too near the top edge. Collect the liquid which passes through the paper, i.e. the filtrate, in a clean test-tube. You will find that it is still red; no lumps of solid are left on the paper.

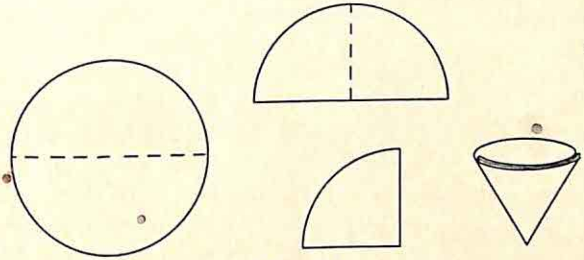


FIG. 49

Now, shake up a little red lead[1] with some water in a test-tube; you will get a red, opaque liquid. This is a suspension of red lead in water; filter it. You will find that the filtrate is clear; the solid is left on the filter-paper.

## What is the purpose of filtration?

A filter-paper is a porous membrane; it contains a large number of very small holes. In the above experiment, the particles of red lead being larger than these holes are kept back by the paper. On the other hand, particles of a dissolved solid, e.g. the dye in red ink, are so small that they can easily pass through the pores of the paper. We use filtration when we wish to remove particles of a suspended solid from a liquid.

---

[1] Red lead is poisonous; avoid getting it on your hands, and be sure to wash before eating.

### Filtration of drinking-water

Bristol has a population of about 450,000. The average daily consumption of water is about 45 gallons per person, making a total of over 20 million gallons per day for the city. All this water has to be filtered, and the Bristol Waterworks Company has filter-beds covering about 10 acres. The filtering medium is a bed of sand (Plate II B).

You can imitate this large-scale method of filtering by obtaining a wide glass tube, fitted with a cork and tube as shown in Fig. 50. In the bottom of the wide tube you should place some pieces of stone about the size of marbles, next a layer of small chippings, then a layer of sand. If you make some muddy water by shaking up a little soil and some tap water, you can test your filter-bed. It will remove the bulk of the mud in suspension. In practice, of course, the water is not so dirty as your specimen and the filter-bed is some feet deep.

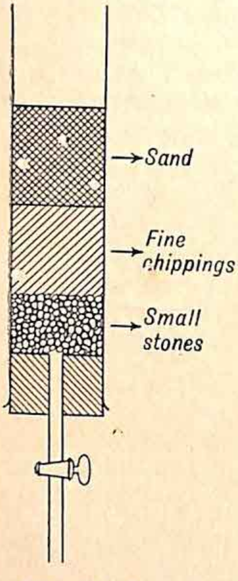


FIG. 50.—Imitation filter-bed

### How can a soluble solid be obtained from a solution?

You know that if you leave some water exposed in a dish in a room the water gradually disappears. The water changes into a vapour, i.e. into a gas-like form below or near the boiling-point; we say that the water evaporates. The warmer the room, the more quickly does the water disappear. If you heat the dish on a gauze over a Bunsen flame and cause the water to boil, it changes into vapour quickly. To obtain solids, which do not vaporize easily, from a solution, we heat the solution in a dish and boil off the solvent. This process is generally called **evaporation.** We use a dish because it gives a large surface to the liquid so that the vapour can escape quickly. Near the end of the operation, heating has to be done carefully to prevent the solid from spurting.

## How can a solvent be obtained from a solution?

Tap water may be suitable for drinking and all ordinary purposes, but it is not pure. As a rule it contains dissolved solids. You can easily prove this by taking say six drops of water on a clean watch-glass (a thin, shallow, glass dish) and evaporating the water over a very small flame; a stain will be left on the glass.

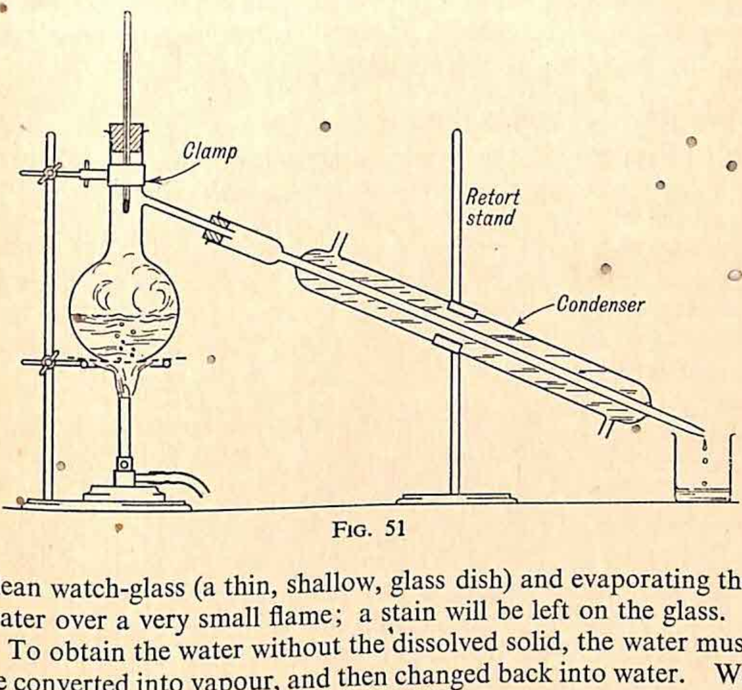


FIG. 51

To obtain the water without the dissolved solid, the water must be converted into vapour, and then changed back into water. We call this process **distillation.** To distil water you can use the apparatus shown in Fig. 51, or perhaps you can devise something simpler, if not so efficient. The apparatus shown consists of a distilling-flask, fitted with a cork and thermometer. The side-tube from the neck of the flask is fitted with a cork into the inner tube of the condenser. The space between the inner tube and outer jacket of the latter is filled with tap water, which is constantly being changed. To do this, rubber tubing connects the tap with the bottom inlet tube; water from the outlet tube at the top is led away by more tubing to the sink. The water to be distilled is kept boiling steadily by putting a small piece of porous pot in the flask; the steam given off on passing into the condenser is cooled and changed back into water. The condensed water trickles down and collects in the receiver; the liquid collected is distilled water. Six drops of this water if evaporated on a watch-glass as indicated above will leave no stain on the glass. Other solvents can be recovered from solutions by distillation using the apparatus in Fig. 51.

### How much do solids dissolve in cold water?

If you take a test-tube about half-full of water, add to it a little salt and shake the mixture, the salt dissolves. Repeating the addition of salt, you will probably find again that the solid dissolves, but further repetition of this process, in time, gives a solution in which no more salt will dissolve. There is a limit to the weight of each solid which will dissolve in a fixed weight of a liquid. When this stage is reached, the clear solution obtained is said to be saturated. Thus by adding salt to water, as indicated, we obtain a **saturated solution** of salt in water.

There is probably no substance which is quite insoluble, but in many cases very little solid is needed to make a saturated solution. The weights of different solids required to saturate equal weights of water differ a good deal. The weight of a solid which will just saturate 100 gm. of water at a particular temperature is the **solubility** of the substance at that temperature. Thus, when we say that the solubility of common salt is 35 gm. at 15° C., we mean that 35 gm. of salt will just saturate 100 gm. of water at 15° C.

We can compare the solubilities of solids roughly in the following manner. Using a small measuring cylinder, 50 c.c. (approx. 50 gm.) of distilled water are measured into each of four clean conical-flasks, each flask being fitted with a cork. As accurately as is possible using a rough balance, 5 gm. of powdered potassium chlorate are weighed and added to flask A. The flask is shaken for some minutes, but some solid remains undissolved. Now, 5 gm. of powdered potassium nitrate (nitre or saltpetre) are added to flask B, which is then well shaken. All the solid dissolves. Another 5 gm. of potassium nitrate are added to the same flask and the shaking repeated. Again the solid dissolves. The process is again repeated, but this time some solid does not dissolve.

The above procedure is repeated using common salt (sodium chloride) in flask C, and sodium nitrate in flask D. As a result of this experiment, we learn that 50 gm. of cold water (approx. 15° C.) will dissolve

less than 5 gm. potassium chlorate,
between 10 and 15 gm. potassium nitrate,
between 15 and 20 gm. sodium chloride, and
over 40 gm. sodium nitrate.

EXPT. 3.—*Does a fixed weight of water dissolve the same weight of solid at different temperatures?*

Take a test-tube about half-full of cold distilled water. Add to it small quantities of potassium nitrate and shake, till you have a saturated solution at room temperature. Now add a little more solid and warm the tube gently. Again add more solid, then heat.

Repeat this procedure, using (*a*) copper sulphate, (*b*) common salt.

## The effect of temperature on the solubility of solids

As a general rule, we can say that **raising the temperature increases the solubility of a solid,** but the extent to which it does so is different for all substances. In the case of common salt, a certain weight of hot water dissolves little more solid than an equal weight of cold water. On the other hand, the solubility of potassium nitrate rises rapidly with rise in temperature.

## Extraction of salt from rock salt

You probably know that a supply of salt is essential for life. How do we get salt? Salt is a **mineral** which occurs in beds in the earth's crust; to a certain extent it is still mined. If you examine a specimen of rock salt, you will probably find that it is rather a dirty-brown colour, certain parts of it looking clear and not unlike glass. How can we make table salt from rock salt? Salt dissolves in water; the earthy matter is insoluble. Is hot water needed? No; it dissolves little more salt than cold water

From what you have already learned, you could obtain a specimen of salt thus. First, powder the lumps of rock salt (say 10 gm.) and shake up well with some water (20–30 c.c.) in a small flask. Next, filter the liquid to remove suspended matter. Collect the filtrate, salt solution, and boil off the water in a dish. The residue is salt fit for consumption.

On a large scale, the process is similar, but as a rule, nowadays, crude salt solution (brine) is pumped from the salt-beds. After removing insoluble impurities, the salt solution is evaporated under reduced pressure or in open pans.

EXPT. 4.—*To find the effect of cooling a hot saturated solution.*

Shake up some powdered alum, or copper sulphate, with some distilled water in a test-tube, until you have a saturated solution of the solid. Now, add another gm. or so of the solid, then warm the tube till the solid has dissolved. Next, cool the tube under the tap and shake the tube vigorously at short intervals. You will find that small particles of solid begin to separate, in fact, solid continues to separate until the solution remaining is just saturated at the temperature of the tap water. Allow the solid to settle, then, pour off the bulk of the liquid left, and finally shake a little of the solid out on to a filter-paper. Press the solid in the folded paper and examine it with a lens or microscope.

The solid which separates from the solution in the above experiment consists of small crystals; the particles have a geometrical shape; the faces are flat and the edges straight lines. All solids which have these properties are crystals, providing they can be, or have been, made by a natural process.

## How crystals are made

When a hot saturated solution of a solid is allowed to cool, as a rule, some of the solid crystallizes out. If the cooling is rapid, the crystals are small; slow cooling gives large crystals.

EXPT. 5.—*To prepare some large alum crystals.*

Take about 100 c.c. of distilled water in a flask and add about 5 gm. of well-powdered alum. Fit the flask with a cork and shake well until the alum completely dissolves. Repeat the addition of alum and the vigorous shaking, until a little solid remains undissolved. (This cold, saturated solution must be prepared carefully, otherwise the experiment will fail.) To this saturated solution add about 5 gm. more alum, then warm the flask till the solid dissolves. Now pour this hot solution into a clean, warm beaker and leave it to cool slowly. In a day or two you will find a few large crystals covered with a saturated alum solution.

If the temperature of the laboratory is steady, it is possible to grow a crystal. Having prepared some crystals as in Expt. 5, the cold, saturated solution is poured into a clean, dry beaker, then a crystal of good shape is selected, and it is suspended in the saturated solution by a thin thread from a wooden splint resting across the top of the beaker. The crystal very slowly increases in size. At a steady room temperature the solution gradually evaporates, and, as it is already saturated, some solid separates. Most of this solid is deposited on the crystal and we say that it grows.

Crystals are also obtained when liquid substances are cooled till they solidify. In this way we get crystals of ice on the windows in frosty weather. If you examine iron objects, e.g. pails, which have been galvanized with zinc, i.e. dipped in the molten metal, you will see that the zinc is crystalline.

When the vapours of some substances are cooled, crystals of the solids are formed. Thus, the violet vapour of iodine condenses to sparkling, blue-black, crystalline plates. Naphthalene vapour when cooled gives shining flakes or crystals; these can often be seen at the base of a chimney when special lighters are used in making a fire. Again, when water vapour is cooled under certain conditions, it gives snow crystals and hoar frost.

## Extraction of Chile saltpetre (sodium nitrate)

This important fertilizer occurs in a mineral, caliche, which is found in certain parts of South America. Considerable quantities of sodium nitrate are extracted by two methods. In the older method, the crushed mineral is boiled for several hours in tanks with the liquor left from previous crystallizations. Insoluble matter is allowed to settle from the concentrated solution, then the clear, hot solution is run into large open tanks, where it is left to crystallize for about 8 days. The remaining solution is run off for further use, then the crystal deposit is dug out and left to dry in the open. In the newer method, the crushed mineral is extracted in large vats (see Plate IIIB) for a much longer period but only at about 40° C. The resulting solution is crystallized by passing it through a series of 20 special cooling tanks. Each tank contains 600 narrow, vertical tubes, through which the nitrate solution flows rapidly, the cooling medium being on the outside of the tubes; in the last six tanks, the cooling medium is liquid ammonia. The crystallized nitrate which clings to the sides of the tubes is removed by a battery of iron rods, then the product is dried in centrifuges.

## The solubility of gases

When experimenting with gases, we collect them in what we call gas-jars, and to keep the gas in the jar, we close the latter with a greased, glass plate. If you were provided with jars of hydrogen chloride, nitrogen peroxide, carbon dioxide and oxygen, you could learn something about their solubilities by opening each jar with its mouth under water in a trough. In the case of hydrogen chloride, the water would rise rapidly in the jar, i.e. the gas is very soluble. Similarly, you would find that the brown gas, nitrogen peroxide, is quite soluble. In the case of carbon dioxide you would find it necessary to shake the jar from side to side, but even then the water would only rise slowly. By shaking up a little water in a closed jar of carbon dioxide, then opening the jar under water, you would see the water "jump" in the jar. Carbon dioxide is fairly soluble. You would not, however, be able to decide whether oxygen dissolves in water or not by this simple method. Oxygen does dissolve, but only to a very slight extent.

Tap water contains dissolved gases; you can see bubbles of these gases separating from the water when you warm it in a beaker or pan. Here, you will note that **the solubility of a gas decreases with rise in temperature**; this applies to all gases which do not react with water chemically.

## Other methods of separating mixed solids

If you add a mixture of lead filings and sawdust to some water, the lead sinks while the sawdust floats. The separation here is due to a difference in density. Flotation, and washing in a stream of water, are often used industrially in concentrating ores. The controlling factor in the separation is not always density alone

Thus, zinc blende, the mineral from which zinc is made, floats in water because it is not wetted, although it is denser than water.

Again, if you make a mixture of iron filings and copper filings, you can separate these substances roughly by using a magnet, which will attract the iron only. In actual practice, the mineral wolfram (from which the metal tungsten is made) is separated from tinstone by a magnetic process. Wolfram is magnetic, tinstone is not.

Sulphur occurs free in nature, but it is mixed with volcanic rock. Now sulphur melts fairly easily when it is heated, whereas the rock does not change, and this fact is used in isolating the sulphur.

## CHAPTER 7

# HOW WE RECOGNIZE SUBSTANCES AND SORT THEM INTO CLASSES

### How do we recognize substances?

Each substance has certain qualities or characteristics which we call properties. In studying these qualities we make use of our senses and note the impressions made on them. For instance, you know that mustard and flowers of sulphur are both yellow powders; but the former has a "hot" taste; coffee is a brown powder with a distinctive smell. By means of colour, smell and taste you can easily distinguish between these solids. Similarly, you know that olive oil is a pale yellow liquid, whereas benzene is colourless. You have no difficulty in distinguishing between benzene and water because benzene has a peculiar smell.

Properties like colour, taste and odour which describe a substance are called **physical properties**; they are qualities which a substance has independently of any other substance. Some physical properties, e.g. density, can be measured; they are often called **physical constants.**

When a little sulphur is heated in an open crucible, it melts and soon catches alight. Sulphur burns with a pale blue flame and produces a gas which has a choking smell. You must have seen petrol burn in a "lighter"; the flame is luminous. When sulphur burns it changes into *one* new substance, while petrol if completely burnt produces *two* new substances; both are in the form of colourless gases, so you do not see them. Properties like the ability to burn, in which a substance changes into one or more new substances, are called **chemical properties.** Chemical changes are brought about by the action of heat, light or electricity, or by the action of some other substance.

The chemical properties of each substance have to be studied separately, but in the case of physical properties it is well to think of them according to a plan or system.

## Physical properties

The following is a list of the more important physical properties, which you need to consider.

*State.*—Is the substance a solid, liquid or gas, under ordinary conditions? If a solid, is it crystalline?

*Colour, smell, taste and touch.*—If a solid is white, we do not learn much about it, but if a solid is blue, like copper sulphate, it belongs to a limited class. Your sense of smell helps you to recognize the gases hydrogen sulphide and ammonia, once you have experienced their odours. You should *never taste chemicals* unless told to do so, but you ought to know that tastes can roughly be classified as sweet, sour, salt or bitter. These, in turn, are the tastes of sugar, vinegar, common salt and quinine. Again, we seldom use touch, but the greasy feel of graphite (black-lead) readily helps us to distinguish it from the metal lead.

*Solubility.*—You are not expected to remember exactly how many grams of a substance dissolve in 100 gm. of water. You ought to know that chalk is insoluble in water, and that salt is quite soluble, even in cold water. That is, you should know the degree of the solubility.

When a substance dissolves, the process is not always physical; the substance may react with the solvent chemically, e.g. in the case of the gas ammonia. Ammonia and oxygen are both colourless gases, but the marked solubility of the former is a striking difference between them.

*Density.*—From a chemical point of view, a knowledge of relative density is often useful. We compare solids and liquids with water; gases with air. Thus, lead is much denser than water, while hydrogen is much less dense than air. You should avoid the words "heavier" and "lighter" (p. 11).

Other physical properties are melting-point, boiling-point, conductivity for heat (p. 193) or electricity, capacity for being hammered into thin sheets (malleability), or being drawn into thin wire (ductility), or alternatively whether the substance is brittle (easily broken).

## The physical properties of iodine and mercury

Using the above scheme as a guide, the following is a statement of the more important physical properties of these substances.

Iodine is a blue-black, lustrous solid, which has a slight smell not unlike sea-weed. It is practically insoluble in water, but it readily dissolves in alcohol, giving a brown solution. Iodine is much denser than water. The solid melts and boils very readily, forming a violet vapour.

Mercury is a silvery liquid, which is insoluble in all common solvents. It is very dense; it boils at a much lower temperature than most metals and it conducts heat and electricity.

From these properties only, you would have little difficulty in identifying these two substances; they are particularly easy examples.

## Sorting substances into classes

If you look about you at the materials which you see every day, you should be struck by the many, varied kinds. Close examination shows that many kinds of matter contain particles of more than one substance. From these mixtures we isolate single substances by the methods indicated in Chapter 6.

It has been found that all **pure substances can be put into two classes.**

Class 1 consists of those substances which it is impossible to split up, by chemical methods, into simpler substances. The substances in this class are called **elements.**

Class 2, a very large one, consists of substances which can be split up into, or which can be made from, two or more of the simple substances in Class 1. The substances in this class are called **compounds.**

You will probably understand the meaning of these terms more easily when you have seen the following experiments.

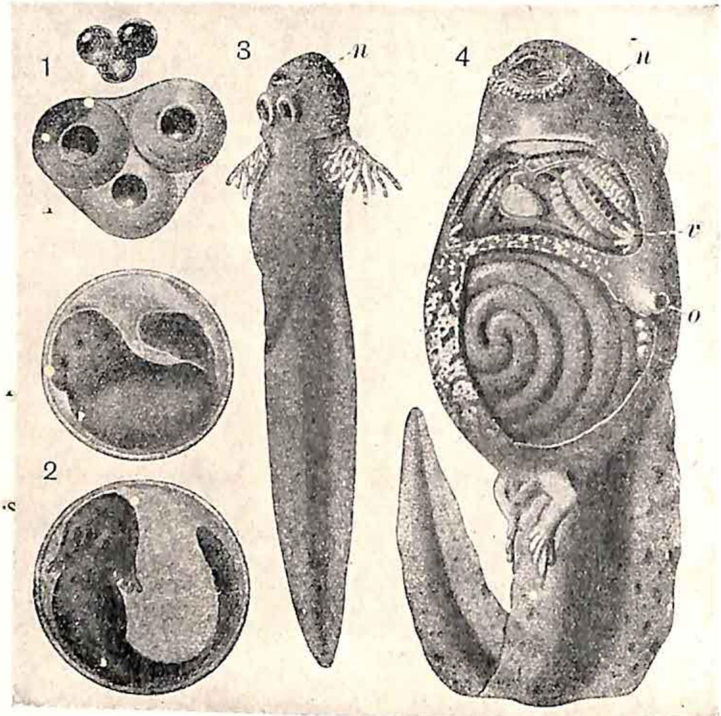
## Some experiments which illustrate chemical change

*Expt. A.*—About 2 gm. of mercury and 2·5 gm. of solid iodine are warmed together carefully in a dry test-tube. The mercury and iodine are both elements, for neither of them has been split up into anything simpler. When warmed together as above, the product, when cold, is a red solid. This substance contains both the mercury and the iodine and we call it mercuric iodide. The mercury and iodine have joined together or combined, as we say, and the product is a compound of the two elements. You

A. Mined caliche being loaded into rail cars for transport to crushing machines

B. General view of works showing extraction tanks (see p. 59)

PLATE IV



The Tadpole (see p. 87)

(1) Three eggs: above, as they are when still in the body of the female; below, as they are in the water, each surrounded by jelly. (2) Tadpoles before hatching out of the eggs. (3) Young tadpoles with suckers, mouth, nose opening (*n*) and outside gills. (4) Older tadpole partly dissected. In (4) the heart, arteries leading to the gills as in a fish, and the gills are seen. In the abdomen is the spiral intestine. *n*, nose opening; *o*, opening from gills; *v*, beginning of front legs. The hind legs are also seen

should note how different the properties of the compound are from those of the elements it contains.

*Expt. B.*—The red solid from Expt. A is removed from the test-tube, if necessary by breaking the tube, and put into a porcelain boat. This boat is pushed into a hard-glass tube fitted as in Fig. 52 (the apparatus should be set up in a fume-chamber). A stream of chlorine[1] is passed through the tube and the boat is heated carefully. A violet vapour, iodine, is seen and close to the boat, a white solid is formed. This is mercuric chloride, a compound of mercury and chlorine.

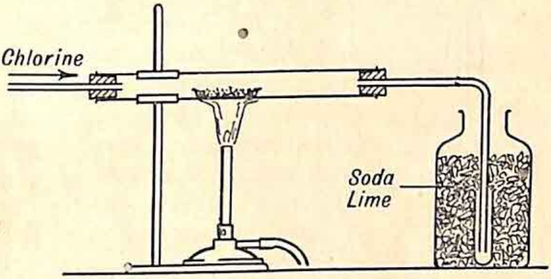


FIG. 52

Chlorine is an element and in this experiment it turns out, or replaces, the element iodine. The chemical change is summed up thus:

> Chlorine and mercuric iodide give iodine and mercuric chloride.

*Expt. C.*—Some mercuric chloride is dissolved in some distilled water, a piece of copper foil added and the solution warmed. In a few minutes, a grey coating is formed on the copper. On rubbing this grey film with a dry filter-paper, a silver coating of mercury is seen. Copper is yet another simple form of matter (an element). It replaces mercury thus:

> Copper and mercuric chloride give mercury and copper chloride.

*Expt. D.*—A solution of copper chloride is poured into a U-tube as shown in Fig. 53. Sticks of carbon pass through the corks and the latter are fixed so that the carbon dips into the solution. The carbon poles are connected to a source of direct current (D.C.), and a current of about 0·5 ampere is passed through the solution.

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[1] See Appendix B, p. 211, for preparation.

One of the carbon poles becomes coated with a red deposit of copper. At the other pole, the gas chlorine is given off; it can easily be detected by its powerful odour.

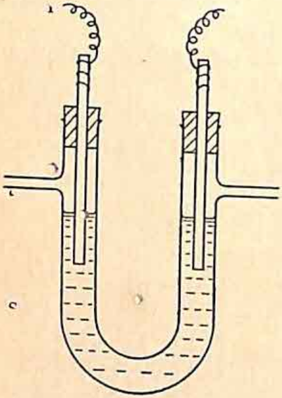


FIG. 53

Here, by means of a current of electricity, we split up a compound, copper chloride, into its constituent elements, copper and chlorine.

*Expt. E.*—Jars of the gases hydrogen and chlorine are put mouth to mouth, and inverted a few times so that they are well mixed. The jars are next separated and closed at once by the greased plates with which they were originally closed. Standing one jar aside, the other is stood mouth upwards, the plate removed and a lighted taper at once applied. There is a violent explosion, and white fumes are seen, especially if the air is damp. The second jar is now exploded so that the product can be observed more carefully. This is a colourless gas which gives the white fumes with the moisture in the air. The colourless gas is hydrogen chloride. In this experiment, hydrogen and chlorine, two elements, combine to produce the compound hydrogen chloride.

*Expt. F.*—To a test-tube about half-full of hydrochloric acid (a solution of hydrogen chloride in water) a few pieces of zinc are added. The tube is warmed and bubbles of a gas are given off (the water is not hot enough to boil); the bubbles form on the surface of the zinc. The mouth of the tube is closed lightly with a thumb, and after a short time brought near a flame, after removing the thumb quickly. The gas burns quietly, or more likely, ignites with a "pop" or "squeak", i.e. a mixture of air and the gas is exploding. The gas which burns is hydrogen.

This experiment is repeated on a larger scale, taking 50 c c. of the dilute acid and several pieces of zinc. The gas is allowed to escape and the reaction to proceed till no more gas is given off.

The solution is next filtered and a few c.c. of the filtrate evaporated in a dish, carefully. The product is a white solid (heating too strongly at the end fuses the solid, which then darkens in colour). This solid is zinc chloride.

Zinc is an element and it replaces the hydrogen in the acid thus:

Zinc and hydrogen chloride give hydrogen and zinc chloride.

*Expt. G.*—Expt. D is repeated using the rest of the zinc chloride solution. This time, leaf-like crystals of zinc are formed on one carbon pole, while chlorine is again set free at the other pole. Thus:

Zinc chloride gives zinc and chlorine.

When a compound is split up into simpler substances, we say that it is decomposed; the reaction is a decomposition, the reverse of chemical combination. Thus, zinc chloride is decomposed by a current of electricity into the elements zinc and chlorine.

## Elements and compounds

Of the substances used in the above experiments, mercury, iodine, chlorine, copper, hydrogen and zinc are elements, i.e. it has not been found possible by the action of heat, electricity or any other means to get two substances out of any one of them. **An element is a form of matter which cannot be split up by chemical means into simpler substances.**

Mercuric iodide, mercuric chloride, copper chloride, hydrogen chloride and zinc chloride are all compounds, i.e. they are substances which consist of more than one element. Further, the elements in them are held together by some kind of force; they are combined and not just mixed together. **A compound is a pure substance consisting of at least two elements which are chemically combined; its properties are entirely different from those of the elements which can be obtained from the compound.** You should note the termination *-ide* in iodide and chloride; as a rule, this shows that the compound consists of two elements only.

## Physical and chemical changes

When a piece of ice is warmed, the solid changes to liquid water. On further heating, the liquid changes into a gas, steam.

On cooling the latter, it condenses to water. Ice, water and steam are the same substance chemically; these changes of state are what we call physical changes. Similarly, if we heat some iodine, it changes into a violet vapour which, on cooling, reverts to solid iodine. In the same way, if we heat mercury, it boils, and the mercury vapour condenses, giving us liquid mercury once again. Both the mercury and iodine change physically.

On the other hand, if we heat mercury and iodine together, we start them combining; these two substances produce one new substance, and the change is chemical. We know that it is new, because it has properties which are different from those of either mercury or iodine. Thus, it is a red solid. Further, it is only possible to get the mercury and iodine back again from it by other chemical reactions. (See Expts. B and C above.)

The differences between physical and chemical changes are summarized in the following table:

| *Physical changes* | *Chemical changes* |
|---|---|
| (1) Easily reversed by reversing the conditions causing the change. | (1) As a rule, not easily reversed, and then only by chemical means. |
| (2) No new substance is formed; the substance has the same composition. | (2) The substance or substances change into one or more new substances. |

### How do we know when a chemical change has taken place?

(1) **We look for different substances**, which we detect by means of their properties. As a general rule, when two substances react, the substances formed have properties very different from those of the original substances. Thus, the yellow-green gas, chlorine, and the red solid, mercuric iodide, give a white solid, mercuric chloride, and a blue-black solid, iodine (violet vapour, when heated). Again, the green solid, copper chloride, can be split up into the red solid, copper, and the gas, chlorine.

(2) **We look for an energy change**, i.e. whether heat, light or sound are produced. As a rule, energy is set free, but sometimes heat is taken up. When coal burns, heat and light are given out; in fact, we use the chemical reactions which take place here to get a supply of heat. When you strike a match, chemical changes take place in which heat and light are evolved. Very rapid

chemical reactions, explosions, are usually accompanied by the production of sound. When a flame is applied to a mixture of hydrogen and chlorine the gases combine explosively.

(3) **Each compound** which is produced **has a fixed composition by weight.** This is true for all compounds, and this general statement or rule is known as a chemical law. We can mix elements in any quantities we please, but when elements combine, they do so in fixed proportions by weight.

(4) When we examine the particles of a compound, we can only see one kind of matter; we cannot see the different elements even with a microscope. On the other hand, when elements are simply mixed, it is usually possible to see more than one kind of matter. Further, in the case of a mixture, it is possible to separate the different kinds of matter by physical means, i.e. by picking, by flotation, by solution and so forth.

## The chemical elements

How many elements are there? After searching for elements since the time of Robert Boyle (*c.* 1660), who was first responsible for our present ideas concerning their nature, chemists have discovered about 90 natural elements. Of these you are not likely to hear of more than 30. Nearly 99 per cent of the matter of which the earth is made consists of about 20 elements, together with compounds composed of two or more of them. It is an extraordinary fact that all the varied substances which we meet can be resolved or broken up into not more than 20 kinds of matter.

The composition of the earth's crust to a depth of some 20 miles, the sea and the atmosphere has been estimated, and the commonest element is found to be oxygen. Approximately half the total weight of matter of which the composition is known is oxygen. The next element in order of abundance is silicon. You only see specimens of this element in laboratories and museums, but its oxide, silica, is familiar to you, e.g. in sand and sandstones; and it is a common substance combined with other compounds in many rocks. Other elements, in order, are aluminium, iron, calcium, sodium, potassium, magnesium, hydrogen, chlorine and carbon. Zinc, copper, lead, tin, silver and gold are well-known elements, but they do not occur so extensively.

### The composition of living matter

The number of elements which, combined in various ways, make up living matter is small. The human body consists of about 65 per cent oxygen, 18 per cent carbon, 10 per cent hydrogen, 3 per cent nitrogen, 2 per cent calcium, 1 per cent phosphorus, together with tiny quantities of the elements potassium, sodium, magnesium, sulphur, chlorine and iron, plus very minute traces of a few others. Most of these elements are found also in other living bodies.

We cannot live without oxygen, which we breathe; we drink water, which is a compound of hydrogen and oxygen. Our bodies cannot make use of free carbon, e.g. in the form of coal, but our food contains sugar, starch and fats, which are compounds of carbon, hydrogen and oxygen. The elements phosphorus and nitrogen we obtain in the form of complicated compounds by eating meat and vegetables.

Plants respire (pp. 166–169) and need oxygen; they obtain water from the soil, together with substances which we call salts (p. 120), which are dissolved in the water. They obtain their carbon from a compound of carbon and oxygen, carbon dioxide, which they get from the atmosphere.

# CHAPTER 8

# LIVING THINGS. HOW PLANTS DIFFER FROM ANIMALS. A SIMPLE ANIMAL AND A SIMPLE PLANT

## Introduction

You already know something about living things. **Knowledge acquired by the study of living things is biology** (Gk. *bios*=life). Anything which you know about the correct way of looking after a pet such as a dog, a canary, a goldfish, any other animal or a plant is biology, but some of the "information" you have picked up about such things may be incorrect. As an example of this incorrect information, it is still often believed that a jackdaw or starling can be taught to speak more easily if its tongue is slit. So we should make sure that our information about living things is correct, by studying them carefully.

## How we know that a thing is alive

In many cases it is not difficult to decide whether a particular object is alive or not. Does it **move**? Non-living things, such as stones, do not move unless some force from outside is applied to them. A hunter who has just shot a lion will judge by its movement whether it is safe to go near it.

A simple test which is used after a man has been rescued from a river is to see if he is **breathing.** Plants as well as animals take in gases from the air and return gases to the air and so are commonly said to "breathe". In the case of plants and some animals there is no muscular movement to cause the exchange of gases. For this reason many scientists prefer to use the word *respire* (see "respiration", p. 160) instead of breathe, particularly when referring to plants.

Living things need **food,** and they pass in shape and in size through the gradual changes which we call **growth.** Of course, a snowball rolling over and over in soft snow also gets bigger, but this is quite a different kind of growth. The snowball merely gets more and more snow packed on to it outside. This is very different from what happens when you drink milk, or eat eggs and bacon, and as a result build up more flesh. Your new flesh is not like the milk, nor the eggs and bacon, but it is formed from these substances by a complicated series of chemical changes.

In the process of living, parts wear out, and have to be replaced. Waste products are formed, such as carbon dioxide, water and urea (a nitrogen compound). Living organisms remove waste by the process of **excretion.**

Another important characteristic of living things is their ability to produce others like themselves. The chestnut tree produces chestnuts from which more chestnut trees can be grown. From the eggs of birds, young birds are hatched, and they grow up into animals similar to their parents. This producing of young plants and animals is called **reproduction.**

Finally, living matter **answers or responds** in some way or another **to outside influences or stimuli.** Animals respond very quickly and obviously to some stimuli, as you see when a person touches something which is very hot. Plants may not answer quite so obviously. It is well known, however, that some flowers, such as daisies, open when they are in the light, but close again in the evening when the light fades.

Thus, living matter has the following characteristics:

(1) It moves.
(2) It breathes, feeds and excretes.
(3) It grows, and reproduces its kind.
(4) It responds to stimuli.

You can probably think of several cases where something which is not alive does **some** of these things. A motor-cycle moves, for instance; it even takes in air and uses petrol, but no one who knows much about it would consider it to be alive. In any particular case where we have to decide whether something is alive or not, it may be necessary for us to consider **all** the above characteristics.

## Plants and animals compared

We divide all living things into two large groups, **plants** and **animals.** In most cases the group to which a particular body belongs is obvious, but, in the case of some of the very smallest and simplest of living things, it is difficult to decide how to group them. You should note that the word "animals" covers not only the familiar dog, cat, etc. but also more simple organisms such as fish, insects, worms and even Amœba (p. 75).

The real distinction between plants and animals lies in the kind of food they need. A **green plant** lives on **water,** which it gets through its roots, a few simple substances called **salts** (p. 120) which are dissolved in the water, and the gas **carbon dioxide** (p. 140), which it gets from the air through openings in its leaves and stems. The green colour of the plant is due to a substance called **chlorophyll;** this is a complicated substance, but the foods are quite simple chemical compounds.

An **animal,** however, does not contain any chlorophyll. For food, it must have complex substances, and it gets them by eating plants, or by eating other animals. Even in the latter case the food really comes from plants. When we eat mutton, the essential foods were really made by the plants upon which the sheep lived.

The other differences between animals and plants are perhaps more obvious, but they are not so important as the method of feeding. An **animal moves about,** but a plant, with its food all round it, only moves parts, as when a flower opens at daybreak. However, a few water-plants do move, and some water-animals move very little, but depend upon food carried to them by the water.

In order to make the best use of movement, an animal needs to be able to detect food quickly, and to move quickly towards it. For these purposes an animal has **sense organs, a nervous system** and **muscles.** The **nose** and **eye** are examples of sense organs. The eye of a vulture enables it to detect a meal, and a dead animal in the desert is quickly covered with vultures which have seen the carcase from a great distance. A rat, though it cannot see what is inside a sack in a dark room, quickly detects food by its smell. The nervous system, or brain and nerves, receives these impressions such as sight, or smell, and sets the **muscles** to work to carry out the movements which are so characteristic of animals. No plant has nerves, sense organs or muscles. The sense organs also help animals to escape being used as food by more powerful enemies. The "scent" of animals like deer is a very well-known characteristic.

**Animals are more compact** than plants. The system of branching roots and stems which help a plant to get its food would merely serve as a hindrance to the movements of an animal.

## How living things are built up

A living thing does not consist entirely of material which is alive. The visible parts of a finger nail, the outer portions of a tooth, and the outermost portion of the skin, are not alive. The actual living substance in animals and plants is called **protoplasm.** The chemical elements in this jelly-like liquid are given on p. 70. They occur, joined together two or more at a time, as certain chemical compounds of which water is the chief.

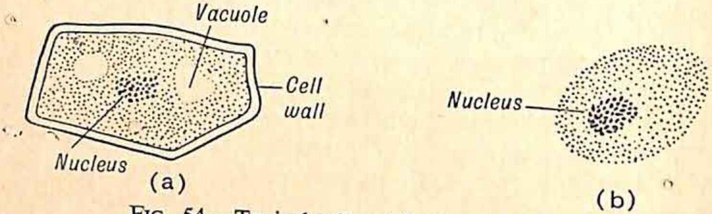


FIG. 54.—Typical cells: (*a*) plant; (*b*) animal

Together with the water there are proteins (p. 150), carbohydrates (p. 147), fats and salts (p. 120). Some of these substances are dissolved in the water, others merely suspended, for particles can be seen under the microscope. Chemical changes which you will consider later take place in this protoplasm, e.g. in respiration (p. 160), in fact, it is continuously being built up and broken down in the bodies of living things. It is important to note that no chemist has yet been able to make this living material from non-living matter.

In many plants the protoplasm is gathered into box-like compartments which are called **cells,** because of their resemblance to the cells of a honeycomb. Each of these plant cells (Fig. 54 (*a*)) consists of the minute mass of protoplasm enclosed in a case of material which is not alive. In many animals the protoplasm is not enclosed in a case of other material, but is just in the form of separate minute masses of protoplasm (Fig. 54 (*b*)). The word "cell" is still used in these instances, despite the absence of any sort of case or covering material. **A cell is the structural unit of**

**which plants and animals are made.** (See Appendix C, p. 212.) In other words, a cell in an animal corresponds to a brick in a house.

With but few exceptions, all cells contain:

(1) A denser mass of protoplasm which is called the **nucleus.**
(2) An outer surrounding mass of protoplasm which is called the **cytoplasm.**

The red corpuscles in our blood are examples of cells which have no nuclei.

## Amœba: an animal which consists of only one cell

This simple animal lives on the surface of the mud in fresh-water ponds. It is so small that we must examine it under a microscope in order to see the different parts, though a very high magnification (use $\frac{1}{3}$-in. objective) is not needed. (See Appendix C, p. 212.)

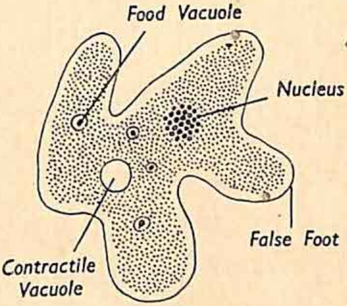


FIG. 55.—Amœba

Each Amœba (Gk. *amoibe* =change) is a single minute mass of protoplasm; a fully-grown one may measure $\frac{1}{100}$ in. in diameter and be just visible to the naked eye. Under the microscope you will see that the living animal is irregular in shape (Fig. 55) and that the shape changes constantly. It consists of a thin and clear outer layer of protoplasm, with an inner layer which is a mass of small granules. There is also an oval portion which is even more granular and distinct. This part is the **nucleus** and it seems to exercise a control over the rest of the animal. Other dark portions are particles of food, and one or more of them is surrounded by a space containing fluid. This is the **food vacuole,** the place where the animal digests (i.e. converts into soluble substances) its food.

Another space in the animal may be seen which slowly expands, and then suddenly disappears; this is the **contractile vacuole.** As these parts are all included in one single cell, Amœba is called a **unicellular animal.** Though so small, it illustrates all the points we have mentioned which are characteristic of living matter (p. 72). Let us see how it does this.

(1) It moves. The animal is always changing its shape (Fig. 56), and it slowly moves as a whole towards any particles of food. Its cytoplasm flows for a time in a given direction, causing a projection or "false foot" to appear, and movement in that direction to take place. More than one false foot may be forming at a given time and the flow may suddenly stop, or reverse itself, or take place in another direction. While the movement is taking place we can see the granules of protoplasm rolling over each other into (or out of) the bulge.

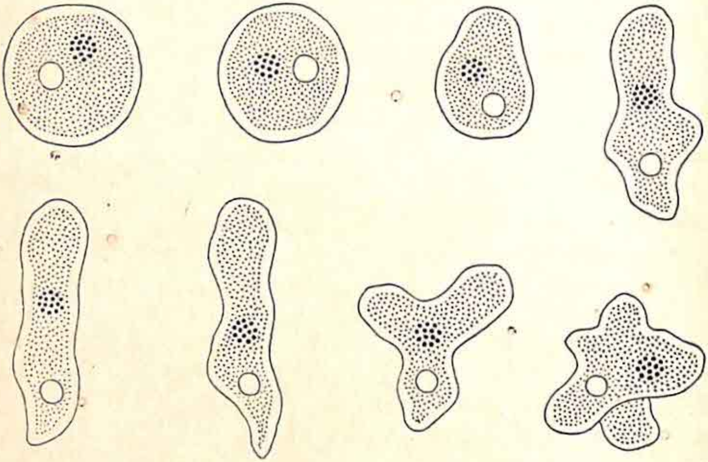


FIG. 56.—Changes in shape of Amœba, drawn at short intervals

(2) It breathes, feeds and excretes. We cannot see it breathe, but Amœba takes in oxygen over its whole surface. To feed, it simply flows round any small food particles and forms a food vacuole round them, in order to kill them if they are alive, and digests them. Any waste material is excreted in a very simple way. Waste water is collected in the contractile vacuole and excreted by being squirted away at intervals. Carbon dioxide and other dissolved substances are excreted with this water.

Carbon dioxide in solution also passes out over the whole surface of the animal.

Amœba gets rid of solid matter which it fails to dissolve by simply flowing away from it, but this is not true excretion as the matter has never really become part of the animal.

(3) It grows and reproduces its kind. As an Amœba lives and feeds, it grows larger. When it reaches a certain size, the nucleus divides into two. Then the rest of the cell gradually divides (Fig. 57) until the two parts, each with a nucleus, form separate small Amœbæ.

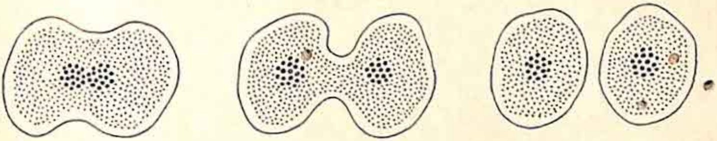


FIG. 57.—Fission of Amœba

(4) It responds to stimuli. Amœba has no definite sense organs, like an eye or nose. It does respond to light, however, as it will move from a dark place towards a lighter one. It also moves away from certain chemicals, such as a drop of an acid.

## Spirogyra : a simple form of plant life

In slow streams or ponds you can often see a rather slimy, bright green mass floating near the surface. It is made up of a large number of threads. If you look at it under a microscope, you can see that each thread is a string of cells, joined end to end, without branching (Fig. 58). The green spiral-band inside each cell contains chlorophyll, and is called a **chloroplast.** Only a low magnification ($\frac{1}{3}$-in. objective) is needed to see this, but if we have a high-power microscope we can make out other details. Each separate cell has a strong outside wall, with a thinner lining inside. This lining is made of living protoplasm, and it holds the **cell-sap,** which is the name given to the clear liquid with which

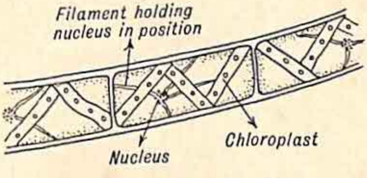


FIG. 58.—Portion of a filament of Spirogyra

the cell is filled. As in most cells, there is a nucleus, though it may be partly hidden by the spiral band.

Like most plants, Spirogyra does not move; it merely floats in the water. Its food consists of water, carbon dioxide and certain salts, all of which are dissolved in the water. Since the chloroplast contains chlorophyll, the plant is able to make the substances it needs from these simple foodstuffs. The cells breathe in oxygen, and breathe out carbon dioxide, which is almost the only waste product.

In Spirogyra we come across a plant which can reproduce by two distinct methods. The first one is similar to that of Amœba. The nucleus of a cell divides into two, followed by division of the chloroplast and the other cell-contents. A fresh cell-wall appears between the two halves, and each half then grows to full length. Sometimes the thread or filament breaks, forming independent plants. The name usually given to reproduction of this type is **asexual reproduction,** since only one cell is necessary for it to take place.

The second method needs two filaments. These form a pair, side by side, almost as if gummed together in some way (Fig. 59). Inside the cells of each, the whole cell-contents leave the cell-walls and shrink into a rounded or oval mass. While this is happening, a bridge gradually forms between opposite cells in the filaments by portions of each cell growing outwards until they meet. When the bridge or canal is complete, the contents of the cells in one filament move across cell for cell, into cells in the other filament. Here, they fuse (or become one) with the contents of the other cell. One filament is now a string of empty cell-cases, and is no longer living matter. The contents of each cell of the other filament develop a coat and burst out of their cell-cases. After a time, each one of these bursts its own coat and starts the growth of a completely new filament or thread of cells. This type of reproduction (conjugation) is an approach to **sexual reproduction** about which you will learn at a later stage.

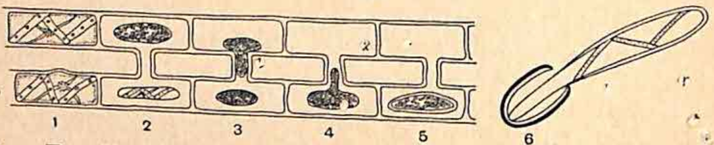


FIG. 59.—Spirogyra showing stages in process of conjugation

## CHAPTER 9

# THE PARTS OF A FLOWERING PLANT

### The wallflower

We will study a flowering plant as an example of a living organism. Its parts are easier to observe than those of an animal. Let us dig up a complete wallflower plant (Fig. 60 (1)), taking care not to damage its roots. To get rid of the soil it is best to wave the plant gently in a bucket of water and then hold it in slowly running tap water. Its chief parts are:

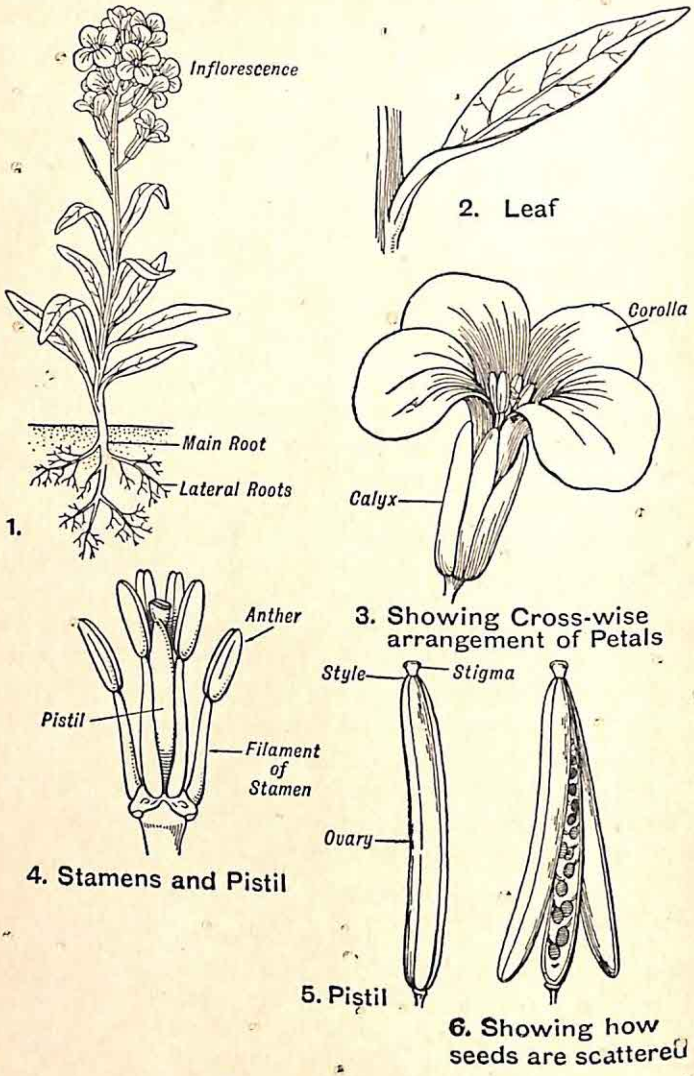
(1) *The root.*—There is a main root which grows downwards; side roots grow outwards from this, and still smaller rootlets from these. You may also see a number of very fine and delicate root-hairs growing out from the surface of the roots, but these will have been torn off unless the uprooting and washing were both carried out very gently. The roots and root-hairs help to give the plant a grip on the soil and prevent it from being easily uprooted. The root-hairs are important for another reason. Each root-hair is a special kind of projection out of a root into the soil; it is through the root-hairs that the plant takes in water and dissolved food.

(2) *The stem.*—This has three functions:

(*a*) It holds the plant up, so that its parts can get air and light.
(*b*) It carries liquids from one part of the plant to another.
(*c*) It forms a structure from which the leaves and flowers spring.

Branch-stems also arise from the main stem.

(3) *The leaves.*—These arise directly from the stem and branch-stems. You will see that they have no stalks (Fig. 60 (2)) and that they are arranged on the stem in a spiral. (In many other kinds of plants, such as nasturtiums, the leaves have stalks.) If you look carefully you will see that the stem also twists. The effect of this twisting, and of the spiral arrangement, is that no leaf is directly beneath another near leaf, and so the maximum area of leaf is exposed to the sun. The leaves of all plants are



2. Leaf

3. Showing Cross-wise arrangement of Petals

4. Stamens and Pistil

5. Pistil

6. Showing how seeds are scattered

FIG. 60.—The wallflower

arranged in some sort of definite plan, with this object, but the arrangement is not always a spiral one.

The main functions of the leaves of a plant are:

(*a*) They afford a means by which gases and vapours enter and leave the plant.

(*b*) They are the part where plant food is built up from simple materials obtained from the air and soil.

You may wonder what a bud is; it is merely a young branch. You will notice that a bud forms in the angle between the stem and a leaf. All stages can be seen, from a small green point to a complete branch. Buds also occur at the ends of stems, and some buds produce flowers, not branches.

(4) *The flowers.*—Towards their ends the stems and branch-stems produce flowers instead of leaves. The whole group of flowers at the end of a stem is called an **inflorescence.**

We shall now look at the parts of one of the flowers (Fig. 60 (3)). You will notice that there are the following four distinct structures:

(*a*) On the outside are four separate leaves called **sepals,** and the whole ring of sepals is called the **calyx.** The calyx is a protective covering for the rest of the flower. Two of the sepals have small pouches in which **nectar** is stored, after it has been made in the real nectary, which is at the base of the short stamens (see (*c*) below).

(*b*) The next ring is the **corolla** and consists of four coloured **petals.** The colour and scent of the petals serve to attract insects to the flower.

(*c*) If you now pull away the sepals and petals you can see a ring of six **stamens** (Fig. 60 (4)), two of which are shorter than the others. Encircling the base of each short stamen is a small, green, hollow sac. In it is a liquid with a sweet taste. It is **nectar** and the place where it is made is the **nectary.**

Each stamen has a stalk or **filament** and a yellow lobe or **anther.** The anther is a box in which the small, yellow grains of **pollen** grow. If some of the flowers you examine are old, you may see that the anther lobes have split open and the pollen is escaping. The function of stamens is connected with the production of fresh plants by means of seeds. Although this is not the case in the wallflower, you will often find in other plants that each stamen carries a **pair** of anthers.

(*d*) The innermost part of the flower is the **pistil** (Fig. 60 (5)). On close examination you can see that it consists of an upper, sticky part, called the **stigma,** which is joined by a short and narrow **style** to a longer and wider portion called the **ovary.** The ovary is in two halves and contains a number of tiny **ovules** which later develop and form **seeds** (Fig. 60 (6)). The pistil, like the stamens, is concerned with the reproduction of the plant.

### Some other parts of plants, and how they help the plants to pass the winter. Annuals, biennials and perennials

If you have even a small acquaintance with gardens you will know that there is a considerable difference in the age to which plants live. Some very familiar garden plants, like the sweet pea, and many wild flowers, like dead-nettle and mustard, carry out their whole life within one year. They grow from seed, flower, form seeds and die within that time. Plants which do this are called **annuals.** Some annuals even go through the whole process more than once in one year, in which case they are frequently weeds which the gardener or farmer finds rather a nuisance. Groundsel and poppies are examples.

In other cases a plant may start from seed one year. During its first year it grows, and forms a store of food, but does not flower. Next year it flowers, uses up its food store, forms seeds and dies. As plants of this kind live two years they are called **biennials.** In many biennials the stored food is useful to us for our own food, or as food for our animals, and we grow the plants for that purpose, using them at the time when the food for the second year has been accumulated. Examples of this type are carrots and turnips.

**Perennials** are plants which live for several years before they die. When they have produced enough food they flower each year, but after the seeds have ripened a store of food is still left, or a fresh one is formed. These plants also survive the winter by drawing on the food store. Daisies, dandelions, harebells and primroses are common perennials. Those perennials which do not form lasting, woody stems are called **herbs** in order to distinguish them from **trees** and **shrubs.**

During the winter the root-hairs of plants become unable to take in water, since they cannot do this when the water is too cold. The preservation of the plant under such unfavourable conditions is called **perennation,** and there are various ways in which it can occur.

(1) Everyone knows that plants like tulips are grown from **bulbs.** Other familiar bulbs are those of the snowdrop, hyacinth, lily and daffodil, while one that you may have investigated yourself is an onion bulb. A bulb (Fig. 61) has layer after layer of thick fleshy leaves, with an outside cover of thinner ones. The thick leaves are a foodstore for a bud in the centre of the bulb. When planted, this central bud grows into next year's stem, leaves and flowers, while roots form underneath on the small disc, which is really the base of the stem. The leaves above ground make food, which passes down to their base, forming the fleshy leaves round the small bud shown in the diagram. When the new bulb is complete, the parts above ground die down again, leaving the new bulb in the ground for another winter.

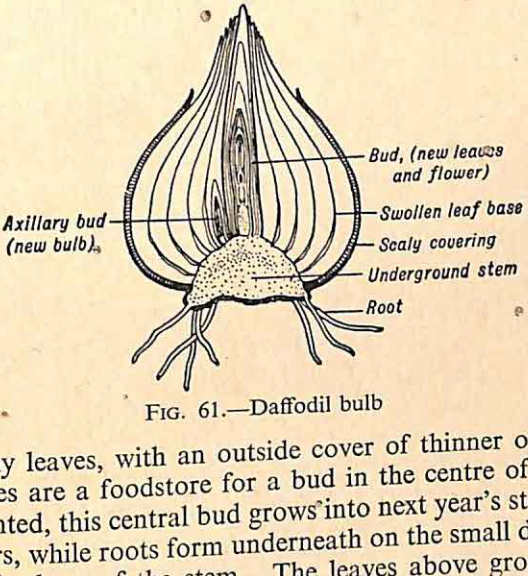


FIG. 61.—Daffodil bulb

(2) Crocuses and gladioli are also grown from a foodstore which some people wrongly call a bulb. But it does not consist of fleshy leaves. It is a part of the actual stem, which is swollen with food at its base, and the leaves only form a thin, scaly

covering. At the top of it is a bud or two. The correct name for this foodstore is a corm (Fig. 62). When the corm begins to develop, roots grow down from its base, and the bud forms a new set of flowers and leaves. As the leaves of the new plant make food, some of it collects at the base of the stem, producing a new corm just on top of the old one. This new corm is complete when the leaves wither, and, as in the case of the bulb, it allows the plant to pass the winter safely. Bulbous crowfoot (buttercup) and lords-and-ladies are common corm-bearing plants.

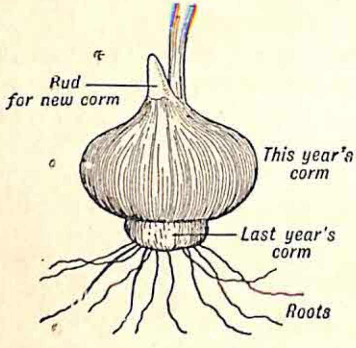


FIG. 62.—Corm of gladiolus

(3) A potato is a swelling on an underground part of the plant, and each eye of a potato is really a form of bud. Since roots do not have buds on them, the potato must be part of a stem which is underground. If you dig up a potato plant (Fig. 63), you will

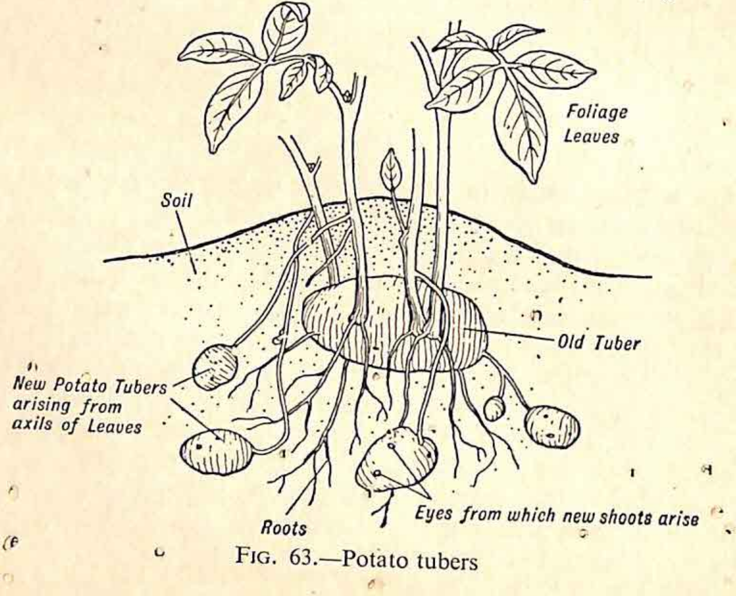

Foliage Leaves
Soil
Old Tuber
New Potato Tubers arising from axils of Leaves
Eyes from which new shoots arise
Roots

FIG. 63.—Potato tubers

be able to see that the real roots are quite distinct from the potatoes, each of which is a swelling or **tuber** at the extreme end of a stem. Some economically-minded gardeners, when planting potatoes, cut each tuber into pieces, with an eye in each piece. Each piece may then give rise to an independent plant which develops from the eye portion. The perennial sun-flower is another example of a plant with a tuberous stem.

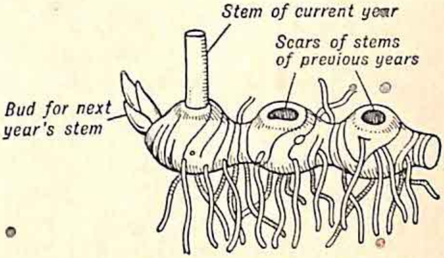


FIG. 64.—Rhizome of Solomon's seal

(4) In many gardens, and sometimes growing wild, you may see the plant called Solomon's seal. It has an underground stem (Fig. 64) which grows horizontally. Each year the plant comes up anew from a spot a little further along this stem, and a bud forms from which the plant of the year after will eventually come. A horizontal underground stem of this kind is called a **rhizome**, and it is frequently swollen along its length with the food reserve of the plant. Wood anemone, iris, bracken and couch grass are other examples.

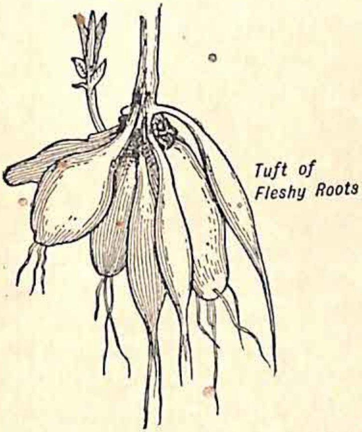


FIG. 65.—Tuberous roots of dahlia

(5) In some plants food is stored in swellings or tubers on the roots themselves. The dahlia is a garden plant with **tuberous roots** (Fig. 65), while wild flowers of this type include orchids and the lesser celandine. You can cut off one of these swellings and set it in the ground to get another plant.

(6) Many trees shed their leaves for the winter, and the dead-looking objects which are then left require much less food, and so can survive the hard times. Evergreens do not of course lose all their leaves at once, but they also live at a much slower rate in the winter.

## CHAPTER 10

# A DESCRIPTION OF THE DEVELOPMENT OF A FROG, AND OF ITS HABITS AND FOOD

### Animals divided into two main groups

If you think of a number of animals, particularly the larger ones and the smaller ones, you may be able to think of a way in which you can divide them all into two large groups. This division (or classification as it is called) depends on whether the animal has the structure usually called a backbone. The scientific name for the backbone is **vertebral column**, and all animals which have one are called **vertebrates**. A few examples of vertebrates are fishes, frogs, snakes, birds and man. Animals which have no backbone or vertebral column are called **invertebrates.** These include the very simplest of animals, which consist of one cell only, and the sponges, worms, spiders, insects and molluscs (like a snail or mussel). We shall now consider one of the vertebrates, viz. the frog, and learn something about its life story and its internal structure.

### The development of a frog

If you take a country walk in early spring, and pass by any shallow pools, you can hardly fail to notice some **frog-spawn.** To form this the female frog poured hundreds of egg-cells into the water, while the male frog similarly poured out an enormous number of much smaller cells called **sperm**-cells. Some of these found and penetrated the egg-cells of the female. As a result, when an egg-cell had been penetrated by one of the sperm-cells, it became fertile, or able to develop in time into a young tadpole. **Fertilization** is thus the process which makes an egg-cell able to develop. It is brought about when the sperm-cell penetrates the egg-cell. This name is given to similar processes, whenever they occur, either in other animals or in plants.

After fertilization a jelly-like covering to each egg-cell swelled up till the whole mass of cells formed the frog-spawn, which is so well known. The real egg is the small black centre, and it is enclosed in the much larger spherical, transparent mass of jelly (Fig. 66 (i)). The jelly protects the egg, because it makes it more difficult to swallow, and it prevents overcrowding of the numerous eggs. The egg is paler on the underside, and contains yolk as a food supply during its development.

With a lens the egg may be seen to develop by a series of divisions, until, after about three weeks, the small black dot becomes a head and tail (Fig. 66 (ii)). Soon after this it wriggles out through the jelly and a tadpole is hatched. When this has just happened you can see masses of the tiny creatures hanging on to pieces of water-weed (Fig. 66 (iii)). A sticky substance for this purpose is made by a **cement gland** on the head. So far, the young tadpoles depend on food stored inside their bodies, and have no mouths. For breathing, two pairs of gills, and later on a third pair, branch from the sides of the head. These are **external gills** (Fig. 66 (iv)). Gills are organs which allow an animal to use air which is dissolved in the water, instead of having to come up to the surface to breathe.

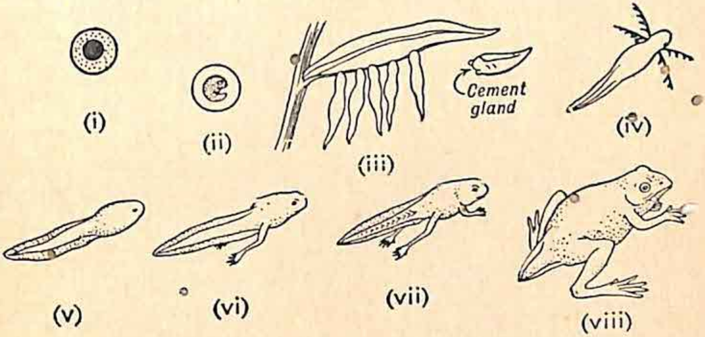


FIG. 66.—Stages in development of a frog

After a day or two the tadpole gets a mouth with a pair of horny jaws, and begins to feed on the plants in the pond. It can now swim about freely by lashing its tail (Fig. 66 (v)). A little later slits, which allow water to pass from the back of the mouth to the outside, form at the sides of the neck. At the same time another set of gills, the **internal gills,** is formed. The tadpole gradually changes over to these for breathing, and the external gills wither away. In many ways it is now like a fish, and cannot live for long out of the water.

Other changes now occur. A fold of skin grows backwards from the head over the openings of the gill-slits and completely closes them except for a small pore on the left side. See Plate IV. Inside, the tadpole's lungs begin to develop. The back legs (Fig. 66 (vi)) soon appear at the sides of the tail, and gradually become more like the legs of an adult frog. The lungs begin to work and take over the function of the gills. Consequently the tadpole keeps coming to the surface and taking a gulp of air. The changes now are rather sudden. The front legs appear (Fig. 66 (vii)) and the internal organs, such as the intestine, alter greatly. The animal becomes carnivorous (meat-eating) instead of vegetarian, and will eat other tadpoles as well as insects or worms. The tail also alters; it gets shorter, and finally disappears. The material of the tail goes to make some of the new parts of the frog: its disappearance is not due, at least in most cases, to its being bitten off. The mouth becomes wider, the eyes larger and the tongue muscular. Finally, the animal, a tadpole no longer, leaves the water and takes up adult life as a frog (Fig. 66 (viii)).

Sudden changes in the life history of an animal occur in many cases. Toads and newts, like frogs, go through a tadpole-stage, and you are probably all quite familiar with the changes of caterpillar into chrysalis, and chrysalis into butterfly.

## How do we recognize a frog?

Suppose we see an animal hopping along. How do we recognize it as a frog? First we have its shape (Fig. 67). We can see an animal which has a head and trunk, but no visible neck or tail. It has short front legs and much longer hind legs, so that it can move in a series of jumps by suddenly straightening the hind legs. Its skin is thin, moist, smooth and slimy. It is very loosely attached to the flesh, and has no feathers, hairs or scales. This moistness of the skin is a very important characteristic and enables us to distinguish it immediately from a toad, which has a dry, warty skin. The colour of the upper parts is mottled brown and green and is much darker than that of the under parts which are often quite a bright yellow. There are five toes on the hind-feet, but only four fingers on the hands or fore-feet. The missing one corresponds to our thumb. On the head we can see very large and prominent eyes, and just behind them a circle of tight skin, the ear-drum. The nostrils are small openings on top of the head, in front of the eyes. The mouth forms an opening which is airtight when closed.

When we examine a frog's front limbs we sometimes find a small lump or pad on the first finger. This tells us the frog is a male. The pad is much more prominent during the early spring than at other times of the year.

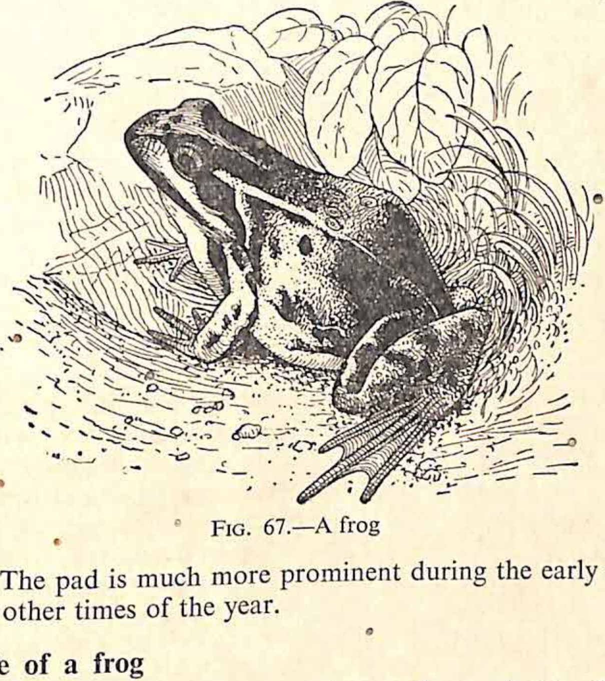


FIG. 67.—A frog

### The life of a frog

We generally see frogs near water or damp places. During the spring we often find them actually in the water where they have gone to lay their eggs. They do not seem to be very sensible about this as they often lay the eggs in small and shallow puddles which soon dry up and kill the spawn. The number of eggs laid by one frog may be anything from one thousand to two thousand. (A toad may lay three times that number.) Their fondness for the damp is connected with the fact that they partly breathe through the skin. If this dries they can no longer breathe through it and may die. In winter, frogs live in a very inactive state in damp, dark places, such as holes in the ground or in rockeries. This period of apparent sleep during the winter is called **hibernation.** Although they like dampness, they cannot live in salt water, and we do not find them or their eggs very near to the sea. Their chief enemies are grass-snakes and certain kinds of birds.

Many people have never heard the voice of a frog. It is a croaking sound which is chiefly heard during the breeding season. If you hear it and wish to see the frog, you may have to look right into the water, as the frog can, and often does, make the noise when it is under water. A captive frog will sometimes croak when someone interferes with it.

Everyone knows that a frog can jump great distances for the size of the animal. If you look at a crouching frog just before it jumps, you will see that its hind legs are bent into a Z-shape. When it straightens these suddenly, a very powerful push is given to its body, and the result is the jump. The short front legs do not interfere with the jump. They are used to hold down any big piece of food, such as a worm, and serve as supports when the frog is squatting.

A frog can swim well. It has webbed toes on the hind-feet, which of course makes them much more useful when swimming. It either lays its front limbs back along the body, or it may use them to make rather feeble strokes when it is only swimming slowly. Although it can swim, a frog will drown if it is kept so that it cannot get out of the water when it wishes. If you keep frogs or breed them from spawn you should remember this, and provide something on to which they can crawl when they wish to get out of the water.

## A frog's food and its capture

People usually give live worms to their pet frogs. Their natural food includes worms, snails and insects. These must be alive and moving or the frog will ignore them altogether. The way they are caught is very interesting. Unlike our tongues, that of a frog is quite free at the back, but the front end is fastened to the lower jaw. It is also covered with a sticky substance. To catch an insect the tongue is suddenly flicked out to its full length, and then back again into the mouth, carrying the insect with it.

Inside the mouth the frog's teeth and eyes prevent its escape. There is a row of teeth round the upper jaw, and two patches of teeth on the roof of the mouth. In addition to these the eyes can press inwards into the top of the mouth and help to grip the food.

## An internal view of the frog

If you look at a frog which has been killed and then dissected from the underside (Appendix C, p. 212), what you can see will be something like the diagram (Fig. 68). Since the frog is lying on its back, the parts which are on your right are on the left side of the frog. This is chiefly of importance later, when the action of the heart is described (p. 151).

The **heart** lies between the two pinned-out, upper limbs and rather lower down. It is somewhat conical in shape and is usually dark red in colour. It may be much paler if blood has been lost during the dissection. Although the frog is dead, it is quite possible that the heart is still beating. Its function is to pump blood round the body and to the lungs. It does this so automatically that, if placed in a salt solution, it may continue to pump, even when it is cut right out of the body.

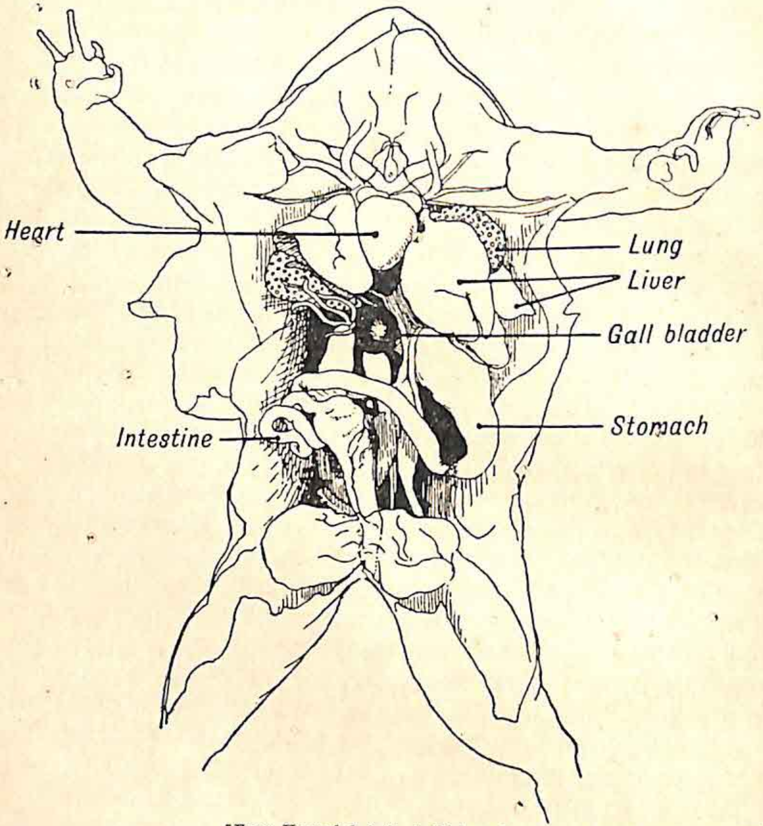
Much the most conspicuous and largest organ is the dark red **liver.** It is in three lobes, and it may be necessary to lift one of these to one side to see the heart. Among many other duties the liver makes a liquid called bile, which is stored in the gall-bladder, a small green organ you can see if you lift the liver a little.

Above the liver the rather puffy, pink and white structures are the **lungs**. Protruding from beneath part of the liver, you can see the end of the stomach as a wide, light-coloured organ. From it, several coils of a narrow tube, the **small intestine,** lead to a much wider part, the **large intestine.** The stomach and intestines are concerned with the digestion of food.

If the frog chosen is a female, you will also see masses of black material. This is in the **ovary** of the frog and later this material becomes the frog spawn.

These are perhaps the most important organs you can see. You may also notice, however, a pale yellow, rather long object, lying between the stomach, intestine and liver. This is the **pancreas,** another part which helps in digestion. The dark red sphere rather lower down than this is the **spleen,** an organ largely concerned with the blood corpuscles, about which you will learn later (p. 151).

Perhaps the frog you are examining is a freshly-killed one, not a preserved specimen. If so, its mouth will be sufficiently flexible for you to bend back its lower jaw. You will then be able to see quite clearly how the back of its tongue is free to be flicked outwards at an insect. The inside of the eye-socket is also very prominent. Behind it, towards the sides, are two openings which lead to the ears. On the roof of the mouth the small central slit leads to the lungs. It is the **glottis.**



[*From Hentschel & Cook*, Biology for Medical Students (*Longmans*)

FIG. 68.—Dissection to show organs of male frog

## CHAPTER 11

# THE SKELETON AND ITS IMPORTANCE. A COMPARISON BETWEEN OURSELVES AND A FROG. MUSCLES AND MOVEMENT

### What is the use of a skeleton?

On p. 86 we learned how animals are divided into vertebrates and invertebrates, and that a frog is a vertebrate. What is the use of a skeleton of bone or similar material? Most of the material of which we and other animals are made is quite soft, or, at least, not rigid. Can you imagine a blancmange as big as a man, or even more, as big as an elephant? It would simply collapse to a flattened-out mass. Our flesh may not be quite as collapsible as a blancmange, but we most certainly could not keep our shape without some sort of rigid structure inside. The skeleton is also a protection. Our brains, which are very delicate parts, are enclosed in a very strong box made of bone. The frog's brain is also protected by bone as are also its organs of smell and hearing.

A very important use of bones is that they give a method of moving the limbs quickly. Inside our forearm are two long bones. When the biceps muscle in the upper arm suddenly pulls on one of these bones the whole forearm and hand are quickly moved to a fresh position.

### A frog's skeleton

We do not need to consider this in great detail. The main thing to notice is the general arrangement (Fig. 69). The skeleton is made up of bones, and of **cartilage** or gristle, which often forms a padding between the bones. It is best

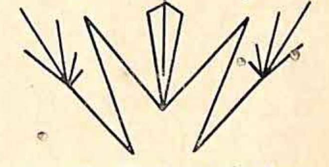


FIG. 69.—Skeleton of a frog (diagrammatic)

to think of the skeleton as a long axis formed of the bones of the head and those of the backbone, spine or vertebral column. There are two girdles attached to this. At the shoulder there is the ring which forms the shoulder-girdle. The fore limbs are fastened to this in such a way as to allow movement. At the lower end is the second ring of bones, called the hip-girdle. To this the hind limbs are attached, also in a way which allows for movement.

The head bones form a protection for the brain, ear and nose. The spine is a rather flexible arrangement of several bones, and you should note that there are no ribs. The very bent Z-shaped arrangement of the long bones of the hind legs is the foundation of the frog's enormous leaping power.

The fastenings which hold bones in position are called **ligaments.** These are strong bands which hold bone to bone, but they are flexible enough to allow them to move.

## The meaning of the word "mammal"

You are all familiar with the fact that we can get large quantities of milk from a good cow. Centuries ago man discovered that certain animals, particularly cows and goats, could be kept by him for the sake of the milk they produced. These animals, of course, really produced the milk originally as food for their young, the calves and kids. Since that time man has so improved the breed of cows that they produce much more milk than is needed to feed their young, and he takes this surplus milk for his own use. Many other animals also produce milk to feed their young. All animals which do this are called **mammals.** You have probably often seen a young lamb rush up to its mother. It usually does this because it is hungry, and the food it gets is milk. A sheep, then, is a mammal. Birds, frogs, fishes and reptiles are not mammals, as they do not provide milk for their offspring. The so-called pigeon's milk is not milk but a substance produced from the lining of the bird's crop. All the other kinds of vertebrates of which you know are mammals. A few familiar examples are rats, kangaroos, tigers, whales, monkeys and man himself. You should note that a whale is a mammal; it is not a fish.

## A frog compared with a mammal

In many ways a frog has points of resemblance to a mammal. As they are both vertebrates you might expect resemblances in their skeletons (Figs. 69, 70), and you would be right. Both of them have the long axis composed of the head and spine, and attached to it the hip and shoulder girdles. Not only are the limbs attached to these girdles in both cases, but the limbs themselves are all built up on the same general plan. This is, to take our own case as an example, upper arm or thigh, elbow or knee joint, forearm or lower leg, wrist or ankle, hand or foot. These same names could be given to corresponding parts in the frog.

In other parts there is also a resemblance; both have a mouth for taking in food and nostrils for breathing. The parts you saw in the dissected frog, such as the heart, liver, intestines and lungs have corresponding parts in all mammals. They are, in other words, built up similarly, and the corresponding parts do the same kind of work. On the other hand, if you examined an animal such as a large insect, which is not a vertebrate, you would find it much more difficult to pick out the parts, as the whole build of a non-vertebrate animal is entirely different.

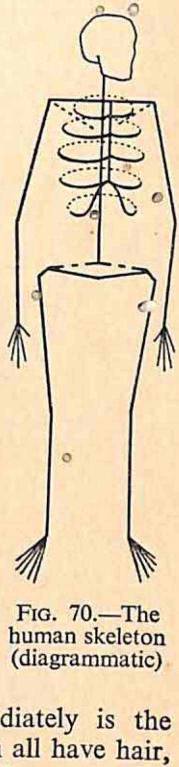


FIG. 70.—The human skeleton (diagrammatic)

There are differences, however, and important ones. If you pick up a frog, one thing you notice at once is that it is cold. A frog is cold-blooded, but mammals (and birds) are warm-blooded (p. 184). Another difference you notice immediately is the smooth slimy skin, as opposed to mammals which all have hair, wool or fur. When the frog's skeleton was discussed, one important difference noted was the absence of ribs. All mammals, like man, have ribs, which help to enclose and protect an air-tight cavity, the chest. In a mammal there is a sheet of muscle, the **diaphragm,** which separates the chest from a lower cavity, the **abdomen.** In the chest are the heart and lungs, while below the diaphragm are the other organs, the liver, the intestines and the

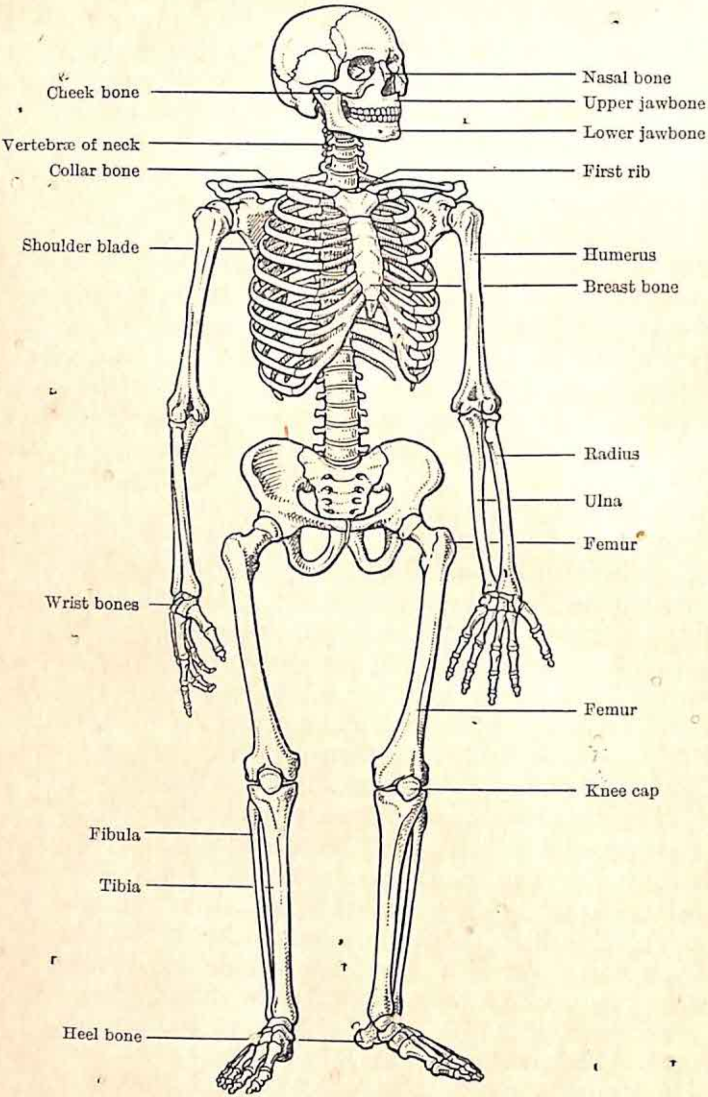


FIG. 71.—The human skeleton

stomach. This is important because it enables mammals to have a much more efficient method of breathing.

## What our own framework is like: the human skeleton

We have already made a simple comparison between our skeleton and that of a frog (p. 95). There are rather more than two hundred bones in the human body, so that it is simpler to consider a part of it at a time. The parts which we shall consider separately are:

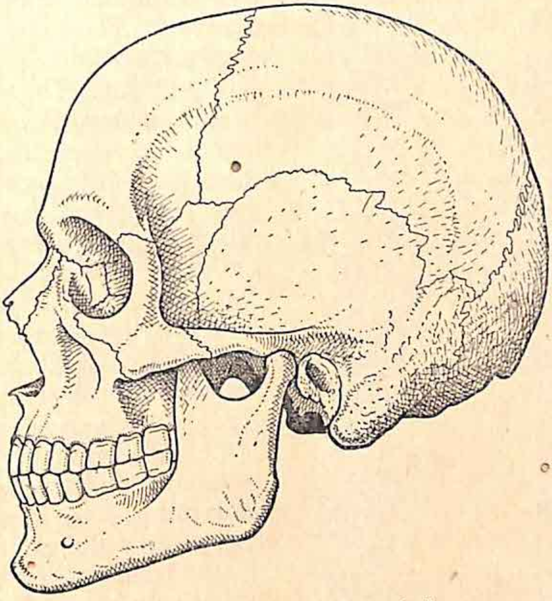


FIG. 72.—Side view of the skull

(1) The head.
(2) The neck and trunk.
(3) The arms and legs.

(1) The whole of the head bones is usually called the **skull** (Fig. 72). The most striking feature is the strong, box-like, upper part, which is the brain-box or **cranium.** It consists of a number of bones which have become so closely joined together

that it is as easy to break the bones as it is to pull them apart. In very early life this is not so, and there are actual gaps which are closed up later to form the strong joints that we see. The purpose of the cranium is to protect the delicate material of the brain. Fixed rigidly to the cranium are the face bones of the upper jaw. The upper jaw is thus immovable. On the other hand we can easily move the lower jaw, since the one bone there, the jawbone, is attached only by ligaments to the other bones of the skull.

(2) The most important bones of the neck and trunk are those of the backbone or **vertebral column** (Figs. 73, 74). Yet another name for it is the spine. It is a number of bones separated from each other by pads of cartilage. The arrangement is something like a pile of cotton-reels placed end to end, though the shape of each bone is not that of a reel. There is, however, a hole running right through the pile, just as there is through the vertebral column. With the exception of the upper two bones, each bone is built on roughly the same plan (Fig. 75). To the front is an arch. This protects a hollow running right down the column from the brain. Inside the hollow is the spinal cord, a very delicate structure made up of nerve cells

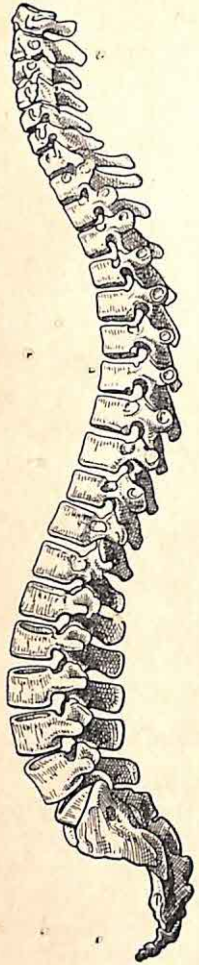


FIG. 73.—The vertebral column viewed from the left side

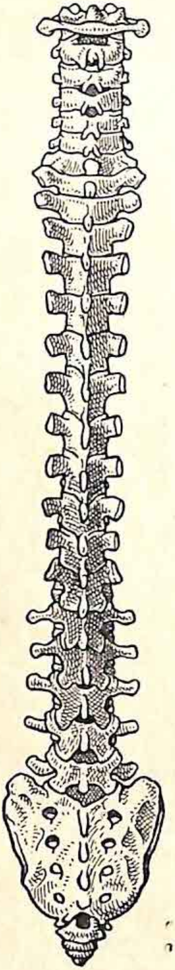


FIG. 74.—The vertebral column viewed from behind

and nerve fibres. At the back of this is a solid mass of bone, from which are three projections, one backwards and two to the sides. These serve to lock one vertebra to the next, and as fixed points on to which the large muscles of the trunk can be fastened. If you run your finger down the middle of someone's back, you can feel the irregularities due to these projections.

The top two vertebræ differ considerably from the others. The top one of all has two hollowed surfaces on which small knobs on the skull can rest and also move a little. In this way the weight of the head rests on the top vertebra, which is therefore called the **atlas.** When the head nods, it rocks backwards and forwards on the atlas. The second vertebra has a vertical peg round which the atlas can rotate. When you turn your head to one side, the skull and the atlas rotate on this second vertebra, which is called the **axis.**

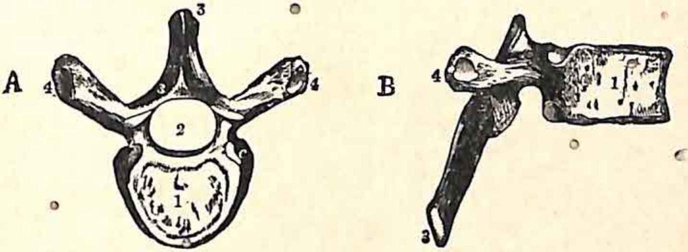


FIG. 75.—A vertebra. A, plan. B, side view

The chest is a hollow cavity in the upper part of the trunk, and is very well protected by the framework of bones (Fig. 76) which forms a strong cage with movable walls. The bones are some of the **vertebræ,** the **ribs** and the **breast bone.** From twelve vertebræ in the back spring out twelve pairs of ribs. The bottom two pairs are only fastened at one end, where they leave the vertebræ. These are called the floating ribs or false ribs. The other ten pairs curve round the chest and either join the breast bone (**sternum**) through strips of cartilage (Fig. 77) or join on to the rib above. The lower ribs are longer than the upper ones, so that the chest is wider at the bottom than at the top.

The remaining bones of the trunk are in two sets, the **shoulder-girdle** and the **hip-girdle** (Fig. 71). The shoulder or **pectoral-**

girdle consists of the shoulder-blades (scapulæ) and collar-bones (clavicles). Each shoulder-blade is a flat, roughly triangular bone, with a socket for the arm-bone, and points where the collar-bone and various muscles are attached. Each collar-bone is fastened at one end to a shoulder-blade and at the other end to the breast-bone. The collar-bone is not very strong, but it serves to keep the arm well back. It seems to get broken rather more easily than most bones, and when this happens the arm falls downwards and inwards, across the body. The shoulder-blade is not fastened to any bone at the back.

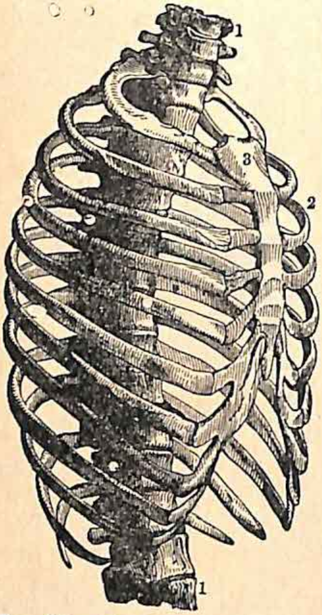


FIG. 76.—The bony framework of the chest viewed from the right side

1, backbone; 2, ribs; 3, breast bone.

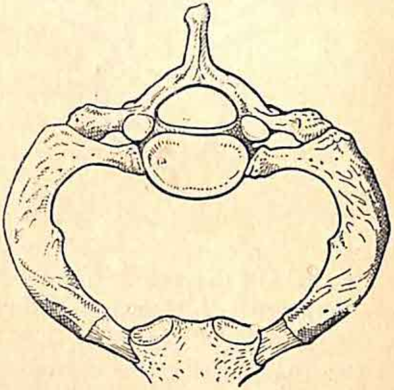
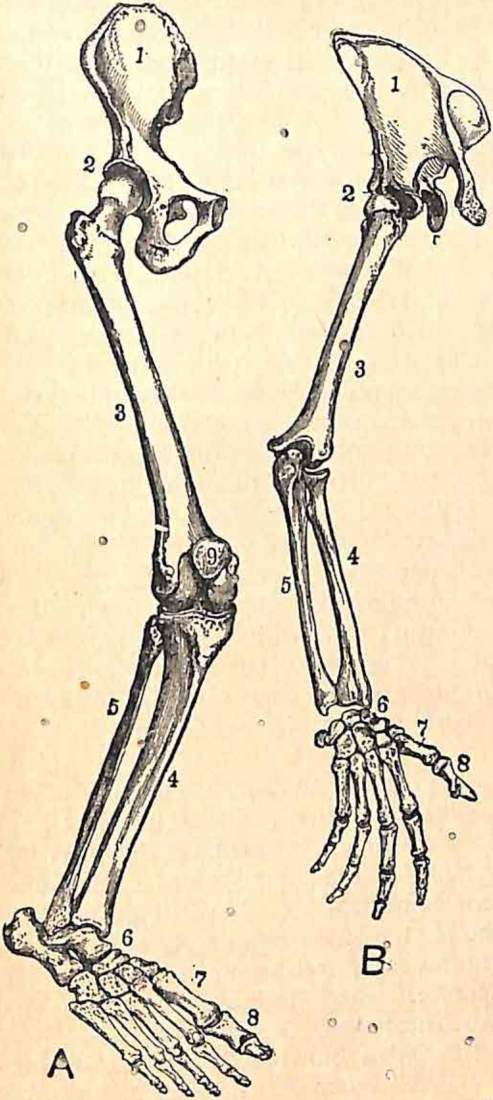


FIG. 77.—A vertebra with a pair of ribs and a part of the breast bone

The hip- or **pelvic**-girdle is a much more substantial structure than the shoulder-girdle. The four bottom vertebræ are fixed rigidly together into one bone, and form a small tail-like structure. The next five above are also joined into one and form a wedge which is jammed into the very massive hip-bones. The hip-bones themselves curve round towards the front of the body and form, with two other pairs of bones, a very strong girdle. This has a shape something like a basin, and serves as a support for the weight



A, *the lower limb.*

1, hip bone.
2, socket.
3, femur.
4, tibia }
5, fibula } lower leg.
6, ankle bones (7).
7, foot bones.
8, bones of toes.
9, knee-cap.

B, *the upper limb.*

1, shoulder-blade.
2, socket.
3, humerus.
4, radius }
5, ulna } forearm.
6, wrist bones (8).
7, bones of hand.
8, bones of fingers and thumb.

FIG. 78.—The limb bones placed for comparison

of the organs in the body above. On each side is a socket for the bones of the leg. It is a much deeper socket than those for the arm-bones, so that the leg is much more strongly attached than the arm. On the other hand, it cannot move so freely in its socket.

(3) There is considerable similarity in the bones of the two limbs. We will look first at the arm and hand (Fig. 78). The single bone in the upper arm is called the **humerus.** At the upper end it has a knob which fits the depression on the shoulder-blade, and forms a joint like a ball and socket. At the elbow this bone forms a joint of a different kind. The forearm contains two bones, the **radius** and the **ulna.** The joint between these and the humerus is more like the hinge on a door. At the wrist there are eight small bones. They are shaped very roughly like cubes, and their arrangement, in two rows, gives great flexibility. In the hand are five long bones, which you can feel quite easily; each finger has three more, but the thumb only has two. If we lay an arm on the table, the palm of the hand facing upwards, the radius and ulna are parallel to each other (Fig. 79). (This position is called supination.) If we now turn the hand so that the palm faces downwards (prone position) the ulna stays where it is, but the radius turns round at its lower end so that it crosses the ulna (Fig. 80). The ability to turn the hand in this way is quite important and enables us to perform many useful movements. Without it, an invention like a screw, for instance, would probably never have been made.

Now compare the bones of the leg and foot with these (Fig. 78). There is one bone in the thigh, the **femur,** with a hinge-like joint between it and two bones, the **tibia** and the **fibula,** in the lower leg. At the ankle there is one bone less than at the wrist, but the bones are larger and one of them forms the heel. The foot has five long bones, like the hand; the big toe has two bones, like the thumb, while the other toes have three each, like the fingers. At the knee, however, there is a difference. The joint here is protected by a small bone, known as the knee-cap. Despite this, it is a joint which often gives trouble, and a blow on it often leads to a swelling and weakness called "water on the knee". Another difference is that the tibia and fibula do not cross like the arm bones if we twist our leg round as far as it will go. Actually they are each fixed at both ends, and we cannot turn our feet to anything like the extent we can turn our hands.

## Joints

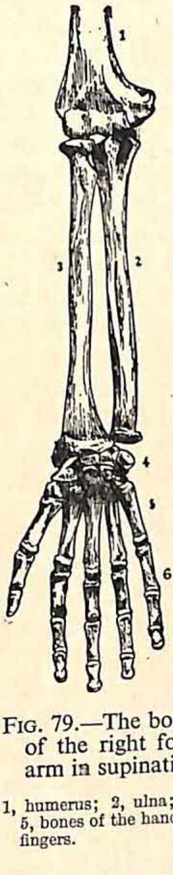


FIG. 79.—The bones of the right fore-arm in supination

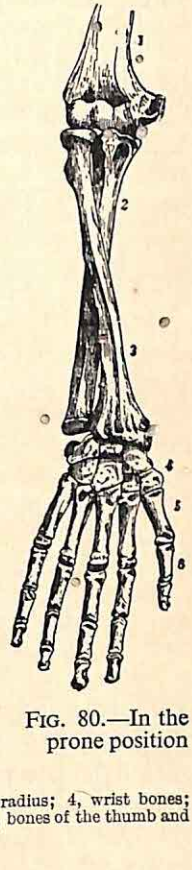


FIG. 80.—In the prone position

1, humerus; 2, ulna; 3, radius; 4, wrist bones; 5, bones of the hand; 6, bones of the thumb and fingers.

The junction of two bones is known as a joint. It is quite obvious that some of our joints, at least, must allow movement between the bones or we should be stiff and rigid, like one of the cheaper kinds of toy soldiers. As bone itself is a rather rough kind of material, movable joints have a layer of gristle or cartilage over the layers of bone. The joint is also enclosed in a bag of tough material (Fig. 81), the inside of which contains a liquid to make the parts move smoothly over one another. We may say that it lubricates the joint, the word "oil" not being very suitable since the liquid is more of a watery nature. Ligaments hold the bones in position at the joints (p. 94), but despite this a powerful pull sometimes displaces the bones. When this occurs the joint is said to be **dislocated.** It is very painful until a doctor or someone with the required knowledge pulls it back again. The shoulder is fairly easily dislocated, as the joint there has a very shallow socket, but the hip joint is much stronger as the socket is deeper (compare the two in Fig. 78, p. 101).

Very different kinds of joints exist. At the shoulder we can swing our arm very freely in almost any direction. The joint here is like a **ball and socket** (Figs. 78, 82), while at the elbow it is like a **hinge**, and we can only bend or straighten the arm. Yet another kind is seen in the axis vertebra (see p. 99), which forms a **pivot** joint with the skull and atlas. At the wrist and ankle the small bones can **glide** over each other, thus giving flexibility to the joint. The various vertebræ, on the other hand, can only move by the flexibility of the discs of cartilage between them, so that the amount of movement is very limited. (This, of course, does not apply to the atlas and axis.) Finally, we have the **immovable** type of joint which is found between the bones of the cranium (p. 97, and Fig. 72).

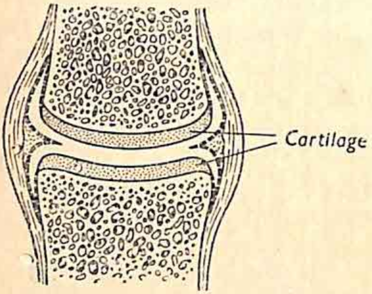
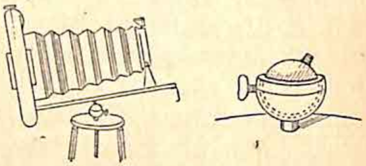


FIG. 81.—Section to show the structure of a joint

The two surfaces of cartilage are in reality touching each other



[*From Andrade and Huxley's* Simple Science (*Basil Blackwell*)

FIG. 82.—A "universal" ball-and-socket joint, and its use with a camera

## Muscles and movement

Most movement in the body is brought about by muscles. If an animal, such as a frog, is skinned, we can get a very good view of many of its muscles. The muscle or flesh of an animal is the part we eat as meat. It generally seems to be red in colour, but this is due to the blood in it. If a piece of beef is kept for a long time in cold water, it gradually becomes paler as the blood dissolves out. The ordinary domestic fowl does not fly very much, and so the muscles which move its wings do not need a very big supply of blood. These are the breast muscles, and they are cream coloured. The breast muscles of birds which spend more time in flight are dark coloured like the other muscles of their bodies. Further examination of the soaked meat shows us that it is made up of fibres. A muscle consists of bundles containing enormous numbers of fibres, each so thin that it can only be seen separately under a microscope. This gives it great strength, just as a bundle of many thin sticks may be very strong. The actual pull in the arm muscles of a strong man may be nearly a ton, while the calf muscle of a frog's leg has been made to lift a weight one thousand times as great as itself.

A muscle is classified as one of three types, **voluntary**, **heart** or **involuntary**. If we can exercise conscious control over it, it is a voluntary muscle though it does not follow that it only works when we will it to. The action of walking, for instance, is carried out without our having consciously to order each separate movement. The heart muscle will work on its own, as can sometimes be seen when a frog's heart is placed in salt solution. It can be speeded up or slowed down by messages from the brain, but these messages are governed by the requirements of the body, not the will. The remaining muscles not under the control of the will are involuntary muscles. They require stimuli to set them into action but we have no conscious control over them.

## Voluntary muscles

Probably the most familiar of all muscles is the biceps. It is a voluntary muscle. When we wish to do so we can make it contract. This means that it gets **shorter** and **fatter** (not smaller), and as a result the arm is bent at the elbow (Fig. 83). The muscle is fastened at both ends. At the upper end two **tendons** fasten it to the shoulder-blade; at the lower end one tendon fastens it to the radius. The tendons are strong, white and stringy cords, and as the shoulder-blade is relatively immovable, the shortening of the muscle bends the arm by pulling on the radius. Most of the voluntary muscles work in this manner. They are fixed to bones at each end, and their contraction or shortening moves the bone at one end. A simple experiment can be performed to show the force exerted by a contracting muscle.

A frog is killed by pithing it, or cutting off its head, and one leg is skinned. The tendon of the calf muscle is cut through at the heel, and the muscle carefully pulled away from the leg except at the knee. During this and subsequent operations it should be kept moist with 0·6 per cent salt solution. The lower leg is cut away, and the femur is cut through just above the knee, leaving the muscle attached to sufficient bone to be clamped. A strong thread is tied to the lower tendon (the tendon of Achilles), and the bone clamped firmly, passing the thread horizontally to a pulley (Fig. 84). A 50-gm. weight is attached to the other end of the thread. A medical or small induction coil is adjusted to give a gentle tingling when held with wet hands. Two pieces of thin wire are connected to the secondary terminals; these wires are then laid across the muscle, and the current switched on momentarily. The muscle contracts and jerks the weight upwards slightly, but it relaxes on switching

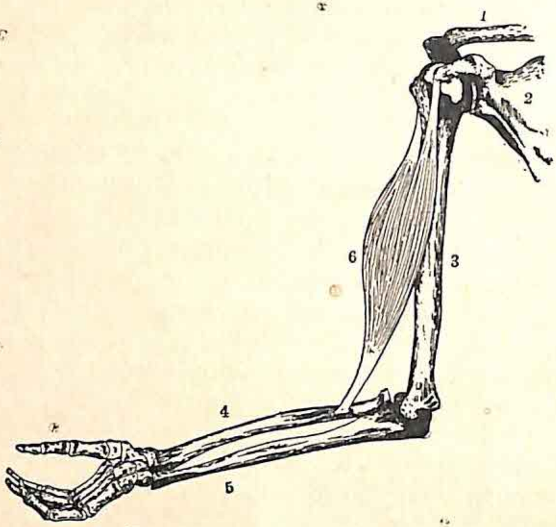


FIG. 83.—Right biceps muscle

1, collar-bone; 2, shoulder-blade; 3, humerus; 4, radius; 5, ulna; 6, biceps muscle. Note its two heads.

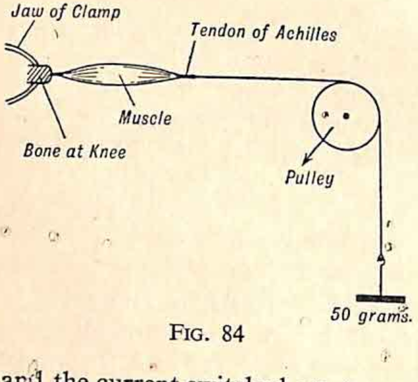


FIG. 84

off the current. The stimulation and contraction can be repeated a large number of times if the muscle has been kept moist continually, provided too strong or too prolonged currents have not been used. A small calf muscle, weighing about half a gram with its attached bone, can be made in this way to move several hundred times its own weight.

Your experience with the frog's muscle in the previous experiment will have shown you that although a muscle can exert a strong pull it is not a hard or rigid body. Consequently it cannot exert a push. Because of this a muscle which has moved a bone, cannot put the bone back into its original position afterwards. This is done by another muscle. The biceps helps to bend the arm. The triceps, on the other side of the humerus, pulls the arm straight again (Fig. 85). Stand on one foot and try to pull the foot of the other leg into a straight line with this raised leg. The calf muscle does the work and you can feel it contract. Now bend the foot upwards as much as possible. The calf muscle relaxes, while the shin muscle (on the outside and front of the leg) contracts. Most voluntary muscles are arranged in opposite pairs in this way, and one member of the pair relaxes when the other contracts. In other cases, the contraction of opposite members of a pair at the same time, serves to hold a part in a steady position, much as a wireless mast or

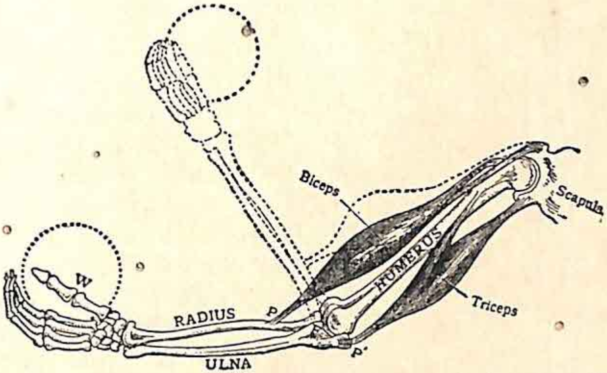


FIG. 85.—To show the action of the biceps and triceps muscles

telegraph pole is supported firmly by opposing sets of taut wires. The erect position of the human body is maintained by many opposing pairs of muscles pulling simultaneously (Fig. 86). When a man is "sand-bagged" or receives a "knock-out" blow on the jaw, the control of all these muscles ceases suddenly; they relax, and he collapses.

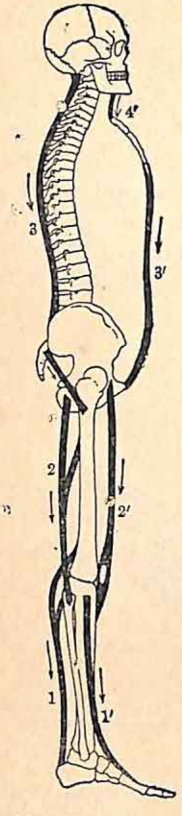


FIG. 86.—How muscles keep the body erect

*Muscles which keep the body from falling forward*

1, muscles of the calf; 2, of the back of the thigh; 3, of the spinal column.

*Muscles which keep the body from falling backward*

1′, muscles of the front of the leg; 2′, of the front of the thigh; 3′, of the front of the abdomen; 4′, of the front of the neck.

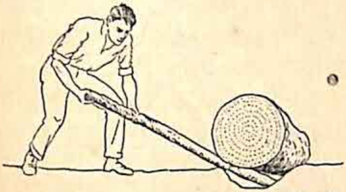
The arrows indicate the direction in which these muscles act

## Involuntary muscles

The involuntary muscles are not joined to bones. One kind is in the form of a circular coat round blood vessels or food pipes. If more blood is required in a given part, the muscles round the blood vessels leading to that part relax, the tubes become wider, and more blood flows. Another kind forms a bag-like organ, the stomach. Regular rhythmic contractions of these muscles help the process of digestion by churning up the food. The iris of the eye is an involuntary muscle which contracts or relaxes in order to control the amount of light which enters the eye.

## Bones as levers

You know that a small boy can balance a bigger one on a see-saw by sitting further from the middle. This is an example of a lever. A rigid body, pivoted at a fixed point, the **fulcrum,** can be moved about that point by weights or forces. Another example of a lever is a crow-bar, by means of which quite large stones or other objects can be moved easily (Fig. 87). There are three different kinds of levers, according to the relative



[*From Andrade and Huxley's* Simple Science (*Basil Blackwell*)

FIG. 87.—Man using crowbar as a lever to move a large log

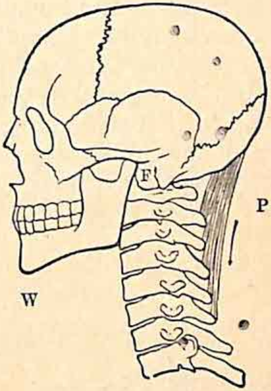
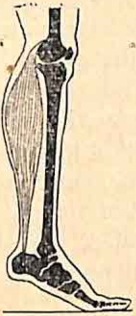
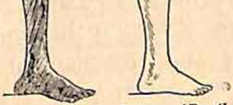


FIG. 88.—The head resting on the atlas

W, weight; P, pull of muscle; F, fulcrum

positions of the fulcrum (F), the weight which is being moved (W), and the weight, pull or push (P) which is used to move it. Examples of all three kinds are known in the body.





[*From Andrade and Huxley's* Simple Science (*Basil Blackwell*)

FIG. 89.—The bones of the foot act as a lever when the heel is raised. The calf muscle pulls on the heel-bone; the ball of the foot acts as the fulcrum, and the weight of the body, pressing down through the shin-bone, is raised

FIG. 90.—Legs of Negro and European compared. Negroes usually have longer heels than Europeans, and need less muscle in the calf of their legs

In the first type the fulcrum is between the weight and the pull. The head resting on the atlas is a good example. Here the weight of the head tends to make it fall forward, but the pull of the neck muscles from the back holds it up, the pivot or fulcrum being the top vertebra (Fig. 88).

In the second type the weight is nearer to the fulcrum than the pull, so that the pull need not be so great. A good example of this is the calf muscle used to lift the weight of the body when we stand on tip-toe (Figs. 89, 90).

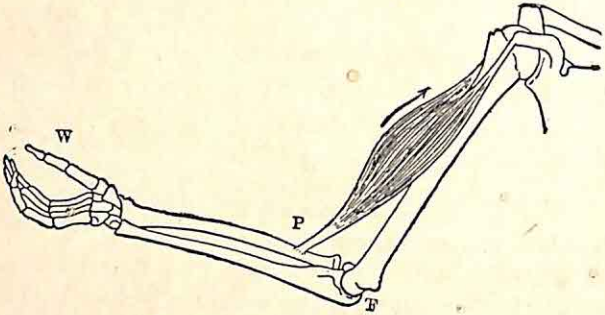


FIG. 91.—Raising the forearm

F, fulcrum; P, pull of biceps; W, weight (something held in hand)

The biceps is an example of the third type. Here a weight held with the hand uppermost is supported by the pull of the biceps muscle on the radius (Fig. 91). Remembering that the little boy balanced the big one by sitting further from the fulcrum, you will see that the weight in the hand must be much less than the pull in the biceps. Actually the pull in the muscles has to be about ten times as great as the weight held, but a small movement of the muscle is much magnified at the end of the arm. Consequently the arrangement gives quick movement rather than great lifting power.

## CHAPTER 12

# ATOMS

### Sorting elements into classes

After examining the physical properties of the elements, we find that it is possible to divide them into two main groups, viz. the **metals** and the **non-metals.**

Elements which we call metals have the following general properties:

(1) They are solid at ordinary temperatures (mercury is an exception).
(2) They shine or can be polished (e.g. a copper kettle or chromium plating).
(3) They can be hammered into thin sheets (e.g. gold-leaf) or drawn into thin wire (e.g. tungsten wire in an electric lamp).
(4) They are dense (e.g. lead).
(5) They conduct heat and electricity well (e.g. copper for boiler-plates and for flex).
(6) They can only be vaporized at high temperatures.

Every metal does not have all these properties, thus zinc is brittle, and in making it, the metal is distilled; it is fairly easily vaporized. But taking this list as a whole, we can easily sort out the common metals from the non-metals. The latter, as a rule, have physical properties which are the reverse of the above. Later, we shall find chemical distinctions. A list of the common elements is given on p. 211, with the classification and other details which you will need later.

### Alloys

You should be careful not to confuse substances like brass, bronze and pewter with the true metals. These solids are metallic in appearance, but they are not elements; they are alloys, i.e. mixtures and in some cases compounds of elements, chiefly metals.

Thus, brass is an alloy of zinc and copper; bronze of copper and tin; pewter of tin and lead. Alloys such as these are made by heating the metals together till they fuse or melt; the intimate mixture of liquids is then cooled.

There is an alloy of bismuth, lead, tin and cadmium which is called Wood's metal; it melts at 71° C. For amusement, spoons are sometimes made of this alloy. The spoons are then given to people to stir cups of hot tea. To their amazement, the spoon melts in the tea. A more serious use of this type of alloy is for the automatic sprinklers with which factories and large stores are equipped in case of fire. If a fire starts in a particular department, the temperature rises, plugs of the alloy melt within the pipes, and water is sprayed from nozzles fixed at intervals to the water pipes which are attached to the ceiling.

## Atoms

You must have heard someone say: "I smashed the thing into atoms", by which you understand that the object was broken into very small pieces. Now, we have very good reasons for believing that all kinds of matter are composed of exceedingly small particles, which we call atoms. At this stage we cannot go into the evidence which supports our belief in these atoms; they are so small that they cannot be seen, which makes things somewhat difficult. To begin with you may think of them as being like very tiny billiard-balls; this billiard-ball conception is not correct, but it is all that we need for the purposes of simple chemistry. You should be familiar with the following assumptions which we make about atoms:

(1) We cannot, in chemical changes, have a particle smaller than an atom. (The word "atom" means indivisible.)

(2) There are only atoms of elements, i.e. about 90 natural kinds.

(3) The atoms of each particular element are exactly alike chemically.

(4) We cannot change atoms of one kind into atoms of another kind in chemical reactions.

(5) Chemical reactions take place between atoms. When elements combine, it is their atoms which join together. In other kinds of chemical change, atoms of different elements are interchanged.

(6) Whenever atoms combine, or they are exchanged, they join together in small, whole numbers.

## Molecules

The word "molecule" means a little mass. You have already found that matter in solution will pass through the very small holes in a filter-paper. Later, you will come across more evidence which favours the assumption we make that all kinds of matter consist of small particles which we call molecules. You have to imagine that if you could look at a substance with a microscope, which would magnify far better than any yet made, you would see these molecules. If you were examining a compound substance, you would see that each molecule contained more than one kind of atom. For instance, in the case of mercuric iodide, you would see 1 atom of mercury and 2 atoms of iodine in each molecule. In the molecules of an element, you would again see more than one atom, as a rule, but the atoms this time would be of the same kind.

**A molecule is the smallest part of an element or compound which can exist free; it is made up of atoms.**

**An atom is the smallest part of an element which can take part in a chemical change.**

## Symbols

A symbol is a sign. In chemistry we have a symbol for each element; **a symbol stands for one atom of an element.** Thus, O stands for 1 atom of oxygen. Wherever possible, the symbol is the first letter of the Latin name of the element. In some cases, several elements begin with the same letter, so that it is necessary to add a second distinguishing letter. Note that the first letter is a capital; the second letter is written in ordinary small type. Symbols for carbon, calcium, copper and chlorine respectively are C, Ca, Cu and Cl.

You should learn the symbols for the elements in the table on p. 211; begin with the less obvious ones—Cu, Fe, Pb, Hg, K, Na.

## Formulæ

In chemistry **a formula stands for one molecule of a substance**, i.e. an element or a compound. The formula for oxygen is $O_2$—we say, "O two"; it means that each molecule of free oxygen contains two atoms. The formula for common salt (sodium chloride) is NaCl; for copper chloride, $CuCl_2$—here, we say "Cu, Cl two" all the letters being pronounced separately. Each molecule of sodium chloride contains one atom of sodium and one atom of chlorine, whereas, in each molecule of copper chloride, we have one atom of copper and two atoms of chlorine. We shall learn how to build up these formulæ a little later.

## Chemical reactions

We have already studied a few examples of chemical change and have summarized the reactions by means of word-equations (see pp. 65–67). You will see the reason for the word "equation" below. You should learn to represent chemical reactions by equations in which formulæ are used instead of words. This brief method of summing up reactions will help you to picture and remember exactly what happens.

On p. 64, we found that mercury and iodine combine to form mercuric iodide. The equation for this reaction is:

$$Hg+I_2 \rightarrow HgI_2$$

or

$$Hg+I_2 = HgI_2.$$

You should note that before we can write an equation, we must know:

(1) The substances which react.
(2) The substances which are formed.
(3) The formulæ of all the substances concerned.

On the left side of the equation, we write the formulæ, in any order, of the reacting substances; on the right side, the formulæ of the products.

We call this symbolic method of representing a reaction an equation, because the total number of atoms of each kind of element is the same on both sides of the equal sign, or of the arrow which indicates the direction in which the change takes place.

Chemical equations merely give the result of a reaction; they do not tell us anything about the properties of the substances concerned, nor anything about the conditions needed for the change to take place. The above equation means, strictly, that one atom of mercury combines with one molecule of iodine (two atoms) to form one molecule of mercuric iodide.

The reactions dealt with on pp. 64–67, may be written thus:

(A) $Hg + I_2 \rightarrow HgI_2$.
(B) $HgI_2 + Cl_2 \rightarrow HgCl_2 + I_2$.
(C) $HgCl_2 + Cu \rightarrow CuCl_2 + Hg$.
(D) $CuCl_2 \rightarrow Cu + Cl_2$.
(E) $H_2 + Cl_2 \rightarrow 2HCl$.
(F) $Zn + 2HCl \rightarrow ZnCl_2 + H_2$.
(G) $ZnCl_2 \rightarrow Zn + Cl_2$.

Do not make a practice of learning equations; later, when you can build up formulæ, try to construct equations in order to visualize what happens in the reactions you study.

## CHAPTER 13

# A SIMPLE STUDY OF ACIDS AND ALKALIES

### An important class of compounds—acids

As substances are discovered, their properties are studied, and those with similar properties are grouped together. We must now learn something about the group of compounds which we call acids. We come across quite a number of acids in ordinary life. For instance, you have probably heard of several of the following: citric acid, the sour substance in lemons; oil of vitriol or sulphuric acid, used in accumulators; oxalic acid, sometimes used for cleaning brass or removing iron-moulds; aspirin or acetylsalicylic acid, a drug; acetic acid, the sour substance in vinegar; carbolic acid, a disinfectant; boric or boracic acid, an antiseptic; spirit of salt or hydrochloric acid, used for cleaning porcelain and for soldering; tannic acid, used for treating burns and in making ink.

You will notice that citric acid and acetic acid have a sour taste; in fact all acids which are soluble in water, and which it is possible to taste, are found to be sour. The word "acid" means sour; the taste of sour milk is due to lactic acid.

Many acids, e.g. citric and oxalic acids, are of plant origin; they are called vegetable acids. Sulphuric acid is made from sulphur or some natural sulphur compound, e.g. iron pyrites, $FeS_2$; hydrochloric acid is made from common salt. Sulphur, iron pyrites and common salt are minerals, and acids made from such substances are called mineral acids.

### The common mineral acids

There are three important mineral acids, sulphuric acid ($H_2SO_4$), hydrochloric acid ($HCl$) and nitric acid ($HNO_3$). They are made as concentrated solutions in water; these so-called concentrated acids are all liquids.

Concentrated sulphuric acid is a colourless, dense, oily liquid, without smell; it contains about 98 per cent of the compound

$H_2SO_4$. This acid is rather a dangerous substance and rapidly corrodes or eats away cloth or flesh. To dilute this acid, it is essential to add the acid slowly to water with steady stirring; during the addition, a good deal of heat is given out.

Concentrated hydrochloric acid is also colourless; it fumes in damp air and has a choking smell; it is a saturated solution of the gas, hydrogen chloride, and contains about 33 per cent of this compound HCl.

Concentrated nitric acid is fairly dense and becomes yellow on keeping in partly-filled bottles, if exposed to light; the acid contains about 66 per cent of the compound $HNO_3$. This acid also fumes and has a peculiar smell; it causes the skin to become yellow and rapidly rots cloth.

No special care is needed when diluting hydrochloric and nitric acids. Whereas the concentrated acids have little in common, you will find that the dilute acids resemble each other in several ways.

## What are the properties of dilute acid solutions?

(1) **Acids have a sour taste.** If you still further dilute any of the dilute mineral acids, it is quite safe to taste a little of the resulting liquid.

(2) **Acids change the colour of the purple dye litmus to red.** One drop only of bench acid will easily effect this change. You can use either litmus solution or paper; the latter is made by dyeing absorbent paper with litmus solution. Litmus paper is usually either red (i.e. already acid) or blue (i.e. slightly alkaline, p. 119). There are many dyestuffs which change their colour with the acidity of the solution; we call them indicators. Some of these you will come across later, but you might like to try some natural colours, like the juice from red cabbage or beetroot, at this stage.

EXPT. 1.—*To investigate the reactions between the dilute acids and some common metals.*

Try the effect of warming each of the three common dilute acids, in turn, with small quantities of zinc, iron and copper in separate test-tubes. When a gas is evolved, collect a specimen in a test-tube (see Fig. 92), then bring the mouth of the tube quickly to a flame to find whether the gas will burn. In some cases you will find that a colourless, inflammable (i.e. it will burn) gas, hydrogen, is set free. When the metals dissolve, note that solution is due to chemical action.

(3) **As a rule acids dissolve metals, while at the same time a gas is set free.** Sulphuric acid and hydrochloric acid are very much alike in their action on metals; nitric acid behaves rather differently. The following table summarizes the results obtained in the above experiment:

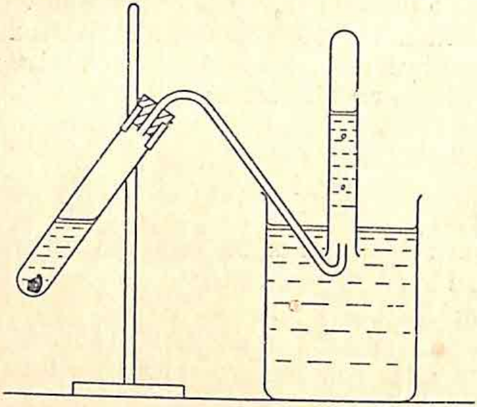


FIG. 92

| | Zinc | Iron | Copper |
|---|---|---|---|
| Sulphuric or hydrochloric acid | Metal dissolves; hydrogen is evolved. | Metal dissolves; hydrogen is evolved. | No reaction |
| Nitric acid . . | Metal dissolves; gas evolved does not burn. | Metal dissolves; gas evolved does not burn; solution becomes orange. | Metal dissolves; gas evolved does not burn; solution becomes blue. |

EXPT. 2.—*To investigate the reaction between the dilute acids and* (a) *washing soda*, (b) *marble*.

Half-fill a test-tube with lime-water. Drop a piece of washing soda into one of the dilute acids contained in a second test-tube. A gas is obviously given off. Hold the two tubes mouth to mouth as shown in Fig. 93. (Be careful not to pour acid into the lime-water.) After a minute or so, close the tube containing the lime-water with your thumb and shake it. The lime-water becomes milky, showing that the gas is carbon dioxide.

Similarly, find what happens when a small piece of marble is added to each of the three common dilute acids.

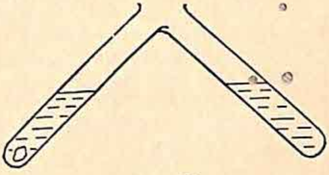


FIG. 93.

(4) **Acids dissolve washing soda (sodium carbonate) setting free the gas carbon dioxide.** A similar reaction takes place with marble (calcium carbonate), but in the case of sulphuric acid the action soon stops.

## Another class of compounds—alkalies

This class of compounds is not a very large one and the substances are not so well known. Caustic soda (NaOH) is used by some people for making soap and for removing fats, e.g. from sink-traps; caustic potash is not common; a solution of the gas ammonia ($NH_3$) in water gives an alkali, ammonium hydroxide ($NH_4.OH$), which is used for washing and cleaning; slaked-lime ($Ca(OH)_2$) is an alkali.

Caustic soda and caustic potash are both white solids which are extremely soluble in water; they are called "caustic" because they corrode or eat away certain substances, e.g. they dissolve wool and attack paint or varnish. Slaked lime is a white solid, which only dissolves slightly in water; the solution is lime-water.

Although the solid substances differ, their dilute solutions have certain properties in common.

## What are the properties of dilute alkali solutions?

(1) **Alkalies have a bitter or soapy taste.** You can safely taste lime-water or a very dilute solution of caustic soda.

(2) **The more soluble alkalies feel greasy**; this is because they attack the skin.

(3) **Alkalies change the colour of red litmus to blue.**

EXPT. 3.—*To investigate the action of an acid on an alkali.*

Take about 20 c.c. (enough to fill a test-tube) of bench caustic soda (sodium hydroxide) solution. Put it into a small beaker and add drops of litmus solution, till you can just see the blue colour. Now add dilute hydrochloric acid, a few drops at a time and stir with a glass rod. At first you will find that the colour remains blue, but a stage is soon reached when the colour begins to change to red. Now, add the acid one drop at a time from a piece of glass tubing. With care it is possible to produce a solution in which the litmus is purple, i.e. neither red nor blue. This solution is neither acid nor alkaline; it is neutral.

Next, boil off the water from the solution in a dish. You will obtain a solid. It is, of course, coloured with litmus, but when you taste a little, you will recognize the solid as common salt.

(4) **Alkalies react with acids to form salts.** If a solution of an alkali is added to an acid solution, carefully, it is possible to produce a solution which is neither acid nor alkaline to litmus. Such a solution is **neutral.** We say that the acid neutralizes the alkali, or vice versa. By neutralizing hydrochloric acid with sodium hydroxide, and evaporating the resulting solution to dryness, as in the above experiment, we are able to isolate a solid; in this case, the solid is common salt. You can repeat the above experiment using sulphuric or nitric acid and either caustic potash (potassium hydroxide) or ammonium hydroxide; in each case you will obtain a solid on evaporating the neutral solution. Each of the solids obtained in this way is known as a salt; common salt is just one member of a huge class of compounds which we call salts.

## CHAPTER 14

# THE AIR AND ITS PHYSICAL BEHAVIOUR

### Has air any weight?

Everyone is familiar with the phrase "as light as air". What does it mean? Is this meaning true in the scientific sense?

We know that air is a form of matter because we pump it into our bicycle tyres and further, we cannot live without it. Feathers, rain-drops and light fragments of paper fall slowly through the air and only in certain circumstances can objects be seen to be in any way supported by it. Very small objects such as tiny particles of dust and pollen may remain suspended in the air for some time—dusty air can usually be detected when a strong beam of light passes through it. But the familiar layers of dust on tables, shelves and pavements show that even many of these fine particles of matter eventually descend and settle on some solid surface. In spite of these everyday observations, the question can only be answered by an experiment designed to weigh a quantity of air.

### How is air to be weighed?

It will be at once evident that any attempt to weigh air will not be as easy as weighing a solid or even a few c.c. of a liquid. Air is a fluid and although it is a simple matter to have a flask full of air, it is not possible to pour out the air and leave the flask empty. The air must be extracted from its container by means of an exhaust pump and the container must be provided with a tap, to be closed or opened as required.

You should note at once that it is impossible to extract all the air from any vessel, i.e. to produce a true vacuum, although many pumps of the type shown in Fig. 94, even when worked by hand, are able to pump as much as $\frac{199}{200}$ of the air out of any container.

Connection between the vessel and the pump is generally made by means of a flexible tube, but ordinary rubber tubing will not serve. As soon as the pump is started, this tubing will collapse; it is then practically impossible to extract any more air. The type of tubing in use is made of rubber, but it has a very thick wall and a relatively small bore. For a reason which will become evident as the work of this chapter proceeds, it is known as pressure tubing.

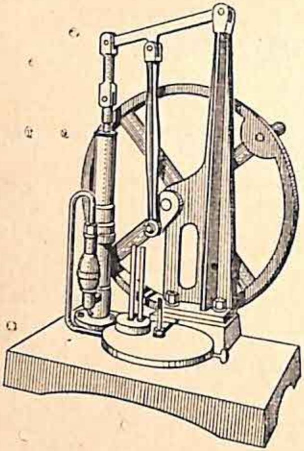


FIG. 94

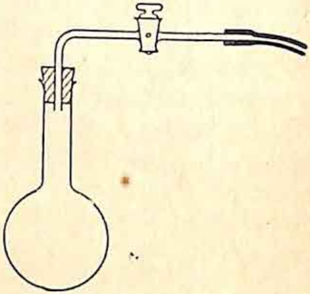


FIG. 95

*Expt. A.—To determine whether air has any weight.*

A strong, round-bottomed flask is fitted with a rubber bung, which carries a short piece of glass tubing in which there is a tap, exactly like a burette tap (Fig. 95). The tap is greased to make it air-tight, and the open end of the tube connected by a length of pressure tubing to the pump. The tap is opened and as much air as possible pumped out of the flask. The tap is then closed, the tube detached from the pressure tubing, and the completely closed and nearly "empty" flask mounted on a beam balance and carefully counterpoised. The flask is removed, the tap opened (the hiss of the inflowing air can plainly be heard), and then remounted on the balance. It is now heavier than the original counterpoise; this can only be due to the single change in the conditions, the introduction of air into the flask.

Air therefore has weight, and careful experiments have been made to find out just what its density is. How would you proceed with the last experiment to find a rough value for the density of air? The air in the room in which you work or in a room at home has a density, expressed in English units, of approximately 1·25 ozs. per cu. ft. You can now calculate the weight of air in any room of which you know the dimensions and find, perhaps with surprise, that it is much greater than you expected.

## Air pressure

One of the distinguishing features of a gas is that it will occupy any space, and this can be accounted for by the freedom of movement of the particles of the gas. Since air has weight it might be assumed that it can exert a pressure. As it can move freely in all directions, you might expect it to be able to exert its pressure in all directions. The following experiments will test whether assumption and expectation are correct.

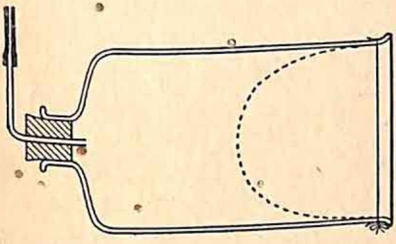


FIG. 96

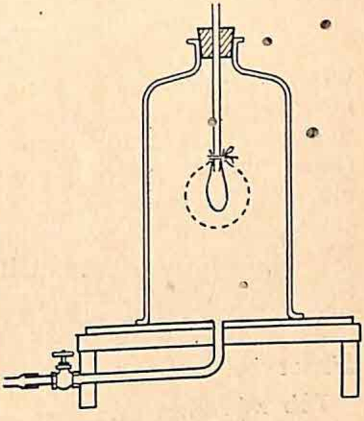


FIG. 97

*Expt. B.*—Over the mouth of a bell-jar a sheet of rubber is securely tied, and the neck is closed by a rubber bung carrying a glass tube connected by pressure tubing to the exhaust pump. Air is then pumped out of the jar, and no matter in what position the jar is held, the rubber sheet is always pushed into it (Fig. 96).

*Expt. C.*—A toy balloon is tied on the end of a short glass tube mounted tightly in a rubber bung which closes the neck of a bell-jar. The ground rim of the jar is well smeared with vaseline and then pressed firmly on a metal plate (Fig. 97) from which a pipe and pressure tubing provide connection to the exhaust pump.

As air is pumped from the bell-jar, the balloon swells and, when well stretched, is almost spherical in shape. What force causes the balloon to expand? *This experiment illustrates the principle of the "Iron Lung" used to operate the lungs of people who are paralysed*, see Plate V A.

*Expt. D.*—Two brass hemispheres (Fig. 98), about 4–5 in. in diameter, with flanged rims, fit closely together to form a sphere. To render this airtight, the flanges are either well greased, or a rubber washer is tightly pressed into position between them. One hemisphere has a handle permanently attached, the other has a connecting pipe and tap on to which a handle may be screwed. This handle is detached, the tap opened and the tightly closed sphere connected by pressure tubing to the exhaust pump. As much air as possible is then pumped out of the sphere, the tap closed, and the sphere disconnected from the pressure tubing. When the handle is replaced, it will be impossible for two boys to pull the two hemispheres apart. If air is allowed to enter the sphere, the two halves may be separated with very little effort.

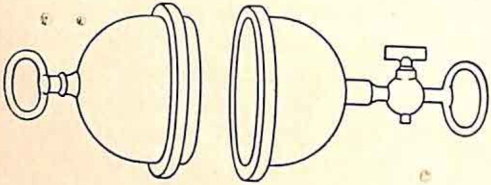


FIG. 98.—Magdeburg hemispheres

## History of this experiment

*This experiment was first performed in* 1650 *at Magdeburg in Germany. It was then carried out by Otto von Guericke to convince people that the atmosphere could exert appreciably large forces. He used two strong copper hemispheres approximately* 15 *in. in diameter, with a leather washer between them to secure an air-tight fit. So long as the complete sphere was full of air, Guericke could pull the two halves apart; but when he had pumped the air out of the sphere, it was found necessary to harness a team of eight horses* (*Plate* VB) *to each half before the separation of the hemispheres could be effected.*

*Expt. E.*—This experiment is performed without the aid of an exhaust pump, yet the result is certainly as impressive as any of the previous ones.

An **air-tight** stopper is first selected for an empty cylindrical ten-gallon oil drum; it is removed and about 2 pints of water poured in. This is heated and boiled vigorously for about 10–15 minutes, when it may be assumed that the air in the drum has been expelled by the steam. As the flame is removed, the drum is closed by the stopper and left to cool. Most of the steam condenses; there is no air inside the drum but the air in the room continues to press on the outside. The result is plainly shown by the reproduced photograph from an actual experiment (Plate VIA).

There is therefore no doubt of the various directions in which air pressure may act. The spherical shape of the balloon in Expt. C (p. 123) indicates furthermore that this pressure is the same in all directions.

## The measurement of air pressure

"Here is the General Weather Forecast for . . ."

"A deep depression off N.W. Ireland. . . ."

"Pressure is high to the W. of Ireland and a trough of low pressure over the North Sea is moving S.E. . . ."

Most of you are familiar with these statements. Have you ever thought what they mean? They not only tell you that the pressure of the air is not the same everywhere, but that there must be some means of measuring it. It is the knowledge of the exact strength of this pressure, and its variation from place to place that allows the preparation of the daily weather forecasts. Any instrument designed to measure this pressure is called a **barometer** and, whether simple or elaborate in design, two types of it are in general use. These are (1) the mercury barometer, (2) the aneroid barometer.

## The mercury barometer

To understand the construction and working of this instrument the following experiments are first performed. In each, a thick-walled glass tube, sealed at one end must be completely filled with mercury. To ensure success in this operation several important details must always receive attention. *The tube and the mercury must be clean and dry*, and the mercury is poured through a small funnel into the tube, until the latter is nearly full. Numerous tiny air bubbles will be seen sticking to the side of the tube. If these are left, the tube cannot be completely filled with mercury. They are removed by closing the open end of the tube with the forefinger and running the air bubble (about 1 cm. long) to the closed end and back again. The forefinger is then removed and the air space at the end of the tube filled with mercury.

*Expt. F.*—A thick-walled glass tube about 2 ft. long, closed at one end, is completely filled with mercury. Using the forefinger to close the open end, the tube is inverted and the lower end placed beneath some mercury in a bowl (Fig. 99). The forefinger is removed: **the mercury remains in the tube**! There is no air in the tube and the air outside is pressing down on the mercury in the bowl. How is the mercury held up in the tube?

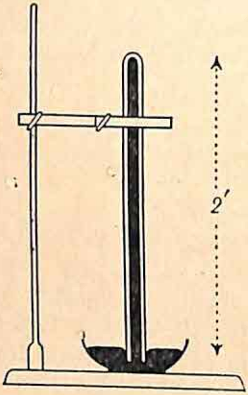


FIG. 99

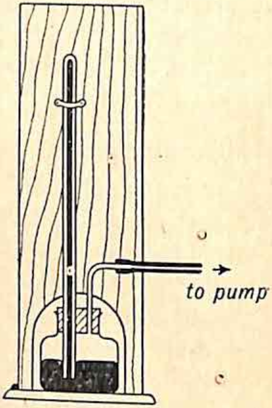


FIG. 100

(*Note that the end of the tube in the mercury does not touch the bowl.*)

If you have some difficulty in appreciating the answer to this question, the following experiment, which is only an extension of the previous one, should clear this up for you.

*Expt. G.*—The bowl in the previous experiment is replaced by a wide-necked bottle, fitted with a rubber bung with two holes in it. The thick-walled tube is pushed through one of these and an ordinary glass tube, bent as shown, through the other. As before, the thick-walled tube is completely filled with mercury and mounted with its open end in the mercury in the bottle (Fig. 100)

Again the mercury remains in the tube. The apparatus is now connected to an exhaust pump to extract the air above the mercury in the bottle. After one stroke of the pump the mercury descends in the tube, and as more and more air is extracted the level of mercury in the tube falls lower and lower. Why does the mercury fall when the air pressing on the mercury outside the tube is gradually removed? The connecting tube to the pump is carefully detached to allow air to enter the bottle and the mercury rises to fill the glass tube as before. Clearly then, the air must exert pressure on the mercury in the bottle, not only to force it up the tube, but also to keep it there.

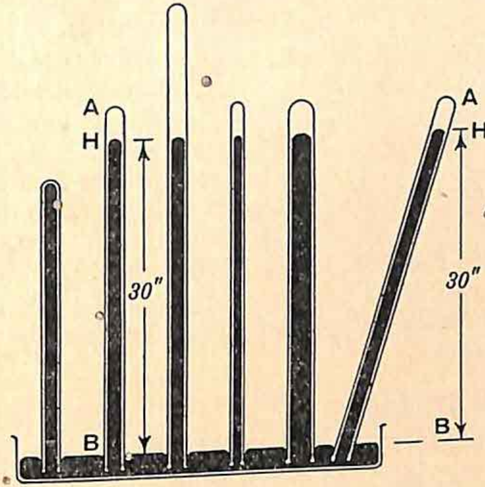


FIG. 101

The following question now arises. If Expt. F is repeated with (a) longer tubes, or (b) wider tubes, will they remain full of mercury? First, a tube about 3 ft. in length is used. The mercury falls slightly but the column of liquid left in the tube is higher than 2 ft. The procedure is repeated with a longer tube; again the mercury falls and to the same level as in the 3 ft. tube. The substitution of wider tubes produces no variation in these observations: a 2 ft. tube remains full, but when the tubes are long enough for the mercury to fall, the heights of liquid remaining are equal, although it is evident that the tubes of differing diameter will contain different weights of mercury. It is therefore the **height** of this column, and *not* its weight, which interprets the pressure of the air.

Measurement of any one of these columns shows this height to be about 30 in. or 76 cm.; the air therefore exerts a pressure which supports a column of mercury 76 cm. high. Briefly, it is usual to express this by saying that the pressure is 76 cm. of mercury. The assembly of bowl, tube (3 ft. or longer) and mercury, according to the method of Expt. F above, constitutes the construction of a simple mercury barometer.

As the air pressure increases, the column rises higher; as it decreases, the column sinks lower. But it should always be remembered that, whatever its height, the column is due to the pressure on the surface of the mercury in the bowl. Therefore, it is from this surface that the height should be measured.

Further, if the tube, e.g. AB in Fig. 101, is tilted to an oblique position, the top of the column at H creeps towards A. Whatever the slope of the tube, the **vertical** height of H above B remains unaltered, until the mercury once more fills the tube. It is therefore the vertical height and *not* the length of the column that must be measured.

## The aneroid barometer

The essential part of an aneroid barometer is a small box, made of thin metal sheet and corrugated so as to respond readily to changes of air pressure on its surface. The box, from which some air has been extracted, is airtight, and the metal is so thin and responsive, that changes in pressure affect, very slightly, its shape. Observations on the box cannot detect such slight changes of shape, so they are "magnified" by a system of cranks and levers, which operate a pointer. This revolves over a circular scale

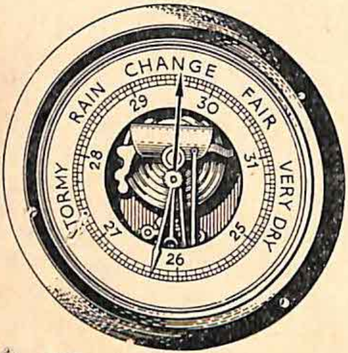


FIG. 102.—Aneroid barometer

PLATE V

A. Patient in a plastic "iron lung" (see p. 124)

B. Guericke's Magdeburg hemispheres experiment (see p 124)

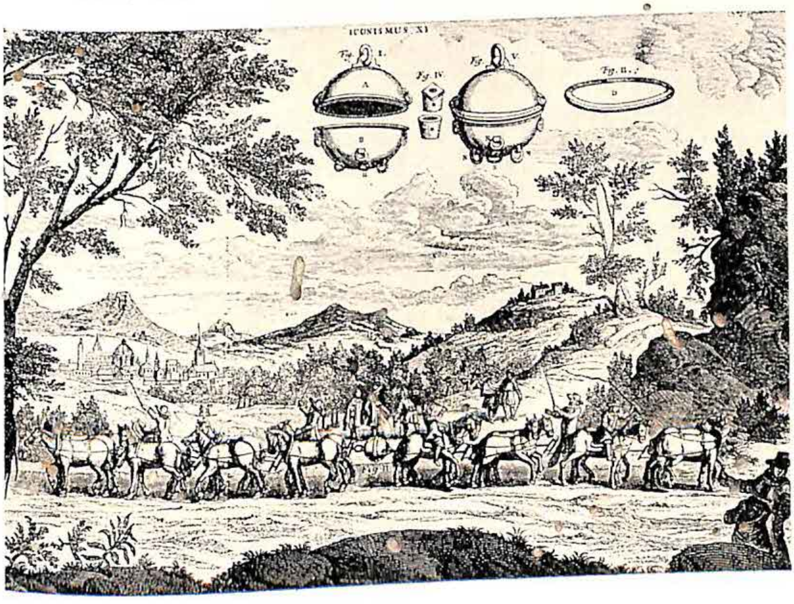
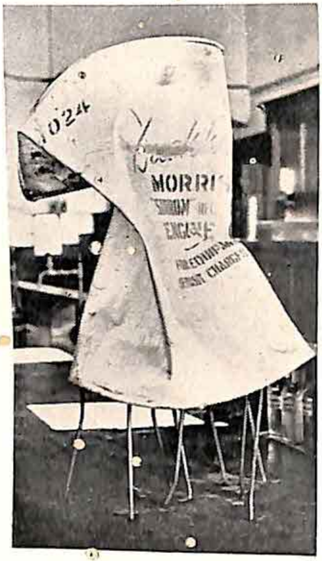
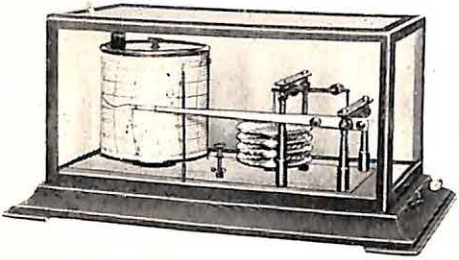

ICONISMUS XI
Fig. I.
A
B
Fig. IV.
Fig. V.
Fig. II.
D

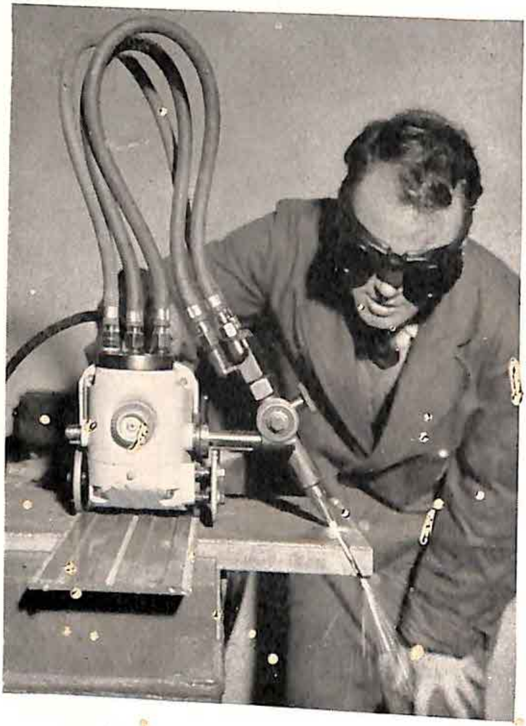
*PLATE VI*



A. Oil-drum crushed by atmospheric pressure (see p. 125)



B. Barograph (see p. 130)



C. Oxygen Machine Cutting (see p. 149)

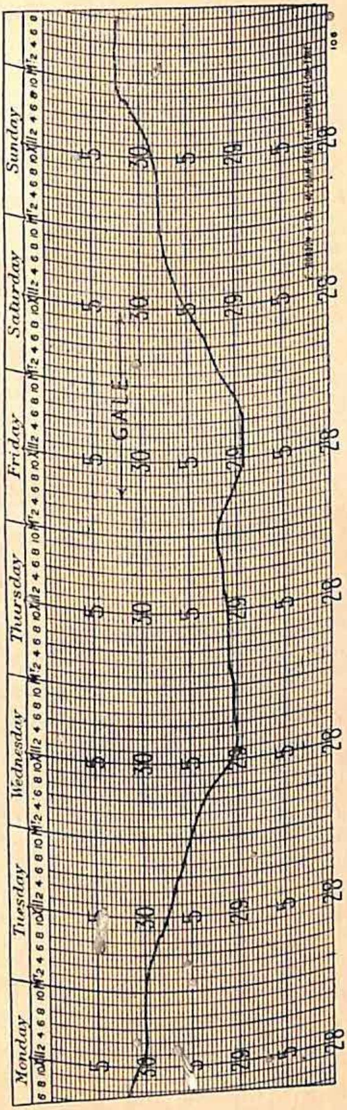


FIG. 103.—Barograph Record.

(Fig. 102) which has previously been graduated to read correctly, by comparison with a mercury barometer.

### Continuous records

A form of aneroid barometer for continuously recording the air pressure is also in use. This is the **barograph** (see Plate VIB): in it, the pointer of the aneroid barometer is replaced by a long light arm (usually aluminium) with a small spouted cup at its free end. In addition, a cylindrical drum, driven by clockwork and having a graduated chart encircling it, revolves just behind the cup. The cup is charged with a small quantity of ink and its spout placed just in contact with the chart. As the box changes its shape, the free end of the arm moves up and down. Since the chart behind it is slowly revolving, the changes in pressure are shown by the wavy line traced upon it (Fig. 103). The chart is divided horizontally for the 7 days of the week, each day being further divided into periods of 2 hours; it is necessary therefore to replace the chart and wind the clock once every week.

### The altimeter

The atmosphere extends many miles up from the surface of the earth. A barometer carried up a mountain reads less than at the base because it has then a slightly shorter (and less dense) air column above it. Up to altitudes of about 8000 feet, the reading falls roughly by 1 in. for every 1000 ft. of ascent. A barometer can thus be used for measuring heights. In an aeroplane an altimeter is used for recording heights. This instrument is essentially an aneroid barometer which is directly marked to indicate altitudes instead of air pressures.

## CHAPTER 15

# THE CHIEF SUBSTANCES FOUND IN THE ATMOSPHERE

### Introduction

In Chapter 14, you studied experiments which are readily explained by the assumption that the earth is covered with a layer of gases, which we call the atmosphere. We divide the atmosphere into two layers, the troposphere and the stratosphere. The **troposphere** is the lower layer in which there is continual movement; it has an average thickness of about 7 miles, contains about 90 per cent of the substances of the atmosphere, and its composition varies very little. The **stratosphere** or higher layer is a calm region, which has a steady temperature; it is explored by ascents in special balloons. In this chapter we shall make a simple study of the composition of the air which surrounds us.

### What is the effect of heating metals in air?

Some metals, like platinum, silver and gold, do not change at all chemically when they are heated in air. If the temperature of these metals is raised sufficiently, they will melt, i.e. they undergo a physical change. Many metals on heating, however, change into new substances quite readily. Thus, if a piece of sheet copper is held, in a pair of old tongs, in a non-luminous Bunsen flame for a few moments, you will find on removing the copper from the flame that it is coated with a black substance. A piece of magnesium ribbon, on heating in a similar manner, begins to melt, catches alight and burns, giving out an exceedingly bright light. As this metal burns, some white smoke is given off and a white ash remains. Similarly, iron acquires a blue-black coating; this coating will fall from a piece of heated iron wire, on bending the wire. It is possible to get zinc to burn, if it is heated very strongly on a thin, iron tray, while a blow-pipe flame is played on the zinc. It changes into a fluffy, white solid, which looks like cotton wool.

These metals, copper, magnesium, iron and zinc, obviously change chemically. They are elements and it seems that the air must be the cause of the change. Can we find any evidence to support this assumption? Magnesium is not a very common metal, but since it burns readily, it is useful for experimental purposes. Now, if magnesium takes up air when it burns, you would expect the white ash it forms to weigh more than the original metal. To test this deduction, you should perform the following experiment.

EXPT.—*Does magnesium gain in weight when it burns?*

Weigh a crucible about half-full of pieces of magnesium ribbon, together with the crucible lid. Support the crucible as shown in Fig. 104. Heat carefully at first, then strongly, with the Bunsen flame slightly to one side of the crucible. Raise the lid with tongs. When the metal burns, replace the lid if too much smoke tends to escape. Note that the lid, which excludes air, stops vigorous burning. Repeat till no flashes of light are seen in the crucible during the heating. Allow the crucible to cool (on the clay triangle) and weigh it again. What do you find?

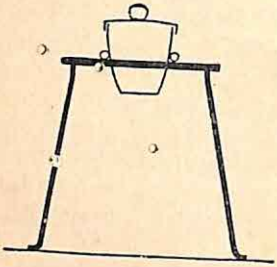


FIG. 104

## The change in weight when metals are heated in air

When magnesium is heated as indicated in the above experiment, there is a distinct gain in weight, which shows that the magnesium has combined with something. Other metals which change in appearance on heating give a similar result.

If this experiment is repeated, the magnesium being covered with dry silver-sand to exclude air, there is no change in weight. Further, on emptying the crucible we find that the magnesium is unchanged.

We conclude that air is the cause of the change which metals undergo when they are heated.

## The burning of phosphorus

Phosphorus is an element. There are two kinds of this element. The white (or yellow) variety is a dangerous chemical; it burns very readily and has to be kept under water. White phosphorus is also poisonous (it is used in rat poison), so that it has to be used with great care, but we shall find it helpful in attacking the problem we set out to solve. The red variety of phosphorus is not poisonous, but it does not burn so easily (p. 145).[1]

*Expt. A.*—To find what is formed when phosphorus burns we proceed as follows. A clean, dry sheet of glass, large enough to cover the mouth of a dry bell-jar is placed on the bench. (It is important that the apparatus should be perfectly dry.) A small piece of white phosphorus is put into a crucible or dish, and the latter placed in the centre of the sheet of glass. With the end of a warm glass rod, the phosphorus is ignited and the bell-jar quickly placed over the burning phosphorus. The latter burns for a time with a yellow flame and gives off dense, white fumes. After a short time this smoke collects into larger particles of a white solid which fall on to the glass plate.

### Does phosphorus combine with air?

*Expt. B.*—To answer this question we must find whether the white solid formed in Expt. A weighs more than the original phosphorus; to do so we proceed in the following manner. A strong, round-bottom flask (500 c.c.) containing a little sand (to protect the flask later) is fitted with a rubber stopper, etc., as shown in Fig. 105. The glass tubing must fit tightly in the stopper, and the small piece of rubber tubing attached to it must be tightly clipped. The stopper is removed while a small piece of white phosphorus is dropped on to the sand. Next, the flask is closed, suspended, by a piece of thin wire round the neck, over the left pan of a reasonably accurate balance, and weighed. Now the flask is warmed carefully till the phosphorus burns (it should then be wrapped in a towel). If the piece of phosphorus taken is too large, you will see that a yellow solid is deposited on the sides of the flask, after the white solid has settled; the yellow

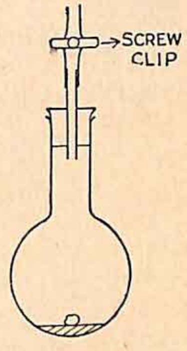


FIG. 105

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[1] White phosphorus should never be handled; it should be cut under water in a dish, and dried with filter-paper.

deposit is unchanged phosphorus. The flask is allowed to cool to room temperature (why ?), then re-weighed. There is no change in weight, indicating that nothing has entered or escaped from the flask. Now, the end of the rubber tube is pinched between the fingers, the clip unscrewed, and the end of the tube released near a small luminous flame. A hissing noise is heard and the flame is seen to move towards the tube. Obviously air has rushed *into* the flask. Why? The flask when re-weighed has gained in weight. We conclude that phosphorus does combine with air.

## Does phosphorus combine with air as a whole?

We shall find the answer to this question by performing either Expt. C or D.

*Expt. C.*—Expt. B is repeated, omitting the weighing. When the flask has cooled to room temperature, the clip is opened with the tube well under the surface of some water in a trough. Some water enters the flask. The clip is closed before removing the tube from the water. It is obvious that only part of the air has combined with the phosphorus. Is the gas still left in the flask air? To test this, the stopper is removed and a lighted taper inserted into the flask. The flame is extinguished at once, showing that the gas is not air. By pouring the water from the flask into a measuring cylinder the volume of air used can be found. Similarly, the total volume of the flask can be measured.

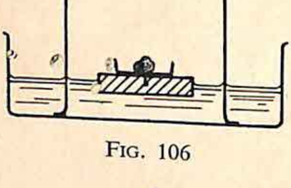

FIG. 106

*Expt. D.*—A trough is about half-filled with water, and a large cork with an inverted crucible lid is placed on the water. After putting a piece of white phosphorus on the crucible lid, a bell-jar is placed over the cork and a bung fitted into the neck of the bell-jar, Fig. 106. The water-level is then marked by means of a rubber band. Next, the bung is removed, the phosphorus ignited by touching it with a hot rod and the bung quickly replaced.

At first, as the phosphorus burns, the water-level inside the jar falls (why?), but in a few moments it begins to rise. The white smoke dissolves in the water. When the bell-jar has cooled to the original temperature, it is obvious that only part of the air has disappeared. Water is now run into the trough till the levels inside and outside the jar are the same, so that no air will enter the bell-jar on removing the bung. On plunging a lighted taper into the gas remaining in the bell-jar, the flame is extinguished. This shows that the gas remaining is not air, and that sufficient phosphorus was used in the experiment to combine with that part of the air which is connected with burning.

The new water-level is marked by a second rubber band. The bell-jar is removed from the trough and inverted, then, by using a large measuring cylinder, the volumes of water required to fill the bell-jar up to the two rubber bands in turn are found.

Expts. C and D show that about one-fifth of the air is used by the burning phosphorus.

## The composition of the air by volume

Air is made up of two chief gases. **One-fifth** of the air by volume is a gas which plays a part in the burning of substances; this gas is the element **oxygen.** The remaining gas, **four-fifths** of the air by volume, consists chiefly of the element **nitrogen.** Air is essentially a mixture of these gases.

You ought to know the names of the more important men of science. In connection with these experiments on air, remember the name of Lavoisier, a French nobleman, on whose work they are based.

Besides oxygen and nitrogen, air always contains *water vapour*, about 1 per cent of the gas *argon*, very small quantities of the gases helium and neon, and about 0·04 per cent of *carbon dioxide*. Variable quantities of other gases like hydrogen sulphide, sulphur dioxide and ammonia are found also, especially in the region of towns.

## Making gases into liquids

When we say that substances like oxygen, ammonia, carbon dioxide and sulphur dioxide are gases, we mean that they exist in this state under ordinary conditions of temperature and pressure.

It is quite easy to obtain liquid sulphur dioxide; all we have to do is to cool the gas sufficiently. Thus, if sulphur dioxide is passed through a U-tube cooled in a freezing-mixture of ice and salt, colourless liquid sulphur dioxide is obtained. A stock of liquid sulphur dioxide is generally kept in schools enclosed in a thick glass "siphon"; the substance remains liquid at room temperature because it is under pressure.

Gases like ammonia and carbon dioxide are easily liquefied by compressing and cooling them at the same time. You must have noticed that air becomes warm when you compress it in pumping up a bicycle tyre. You may have seen near an ice-rink, a zigzag set of iron tubes which are being cooled by water. Usually the water is "steaming" because the pipes contain ammonia which has become hot through compression by a pump. The cold water cools down the ammonia sufficiently for it to change into the liquid state, so long as it is kept under pressure.

Some gases, like oxygen proved difficult to liquefy, until it was found that there is a certain temperature for each gas, below which it must be cooled before it will change to a liquid under pressure. Liquid air is made in large quantities to-day and the process is fairly simple. Air, from which water vapour and carbon dioxide have been removed, is compressed, then cooled, still further compressed and again cooled. The air, now at about 200 atmospheres pressure, is passed through a long spiral tube A (Fig. 107), and allowed to expand through a small valve C into a chamber D. In expanding, the air is cooled a great deal. The cold air is passed through a spiral tube B which surrounds that through which incoming gas is passing, thus cooling the latter.

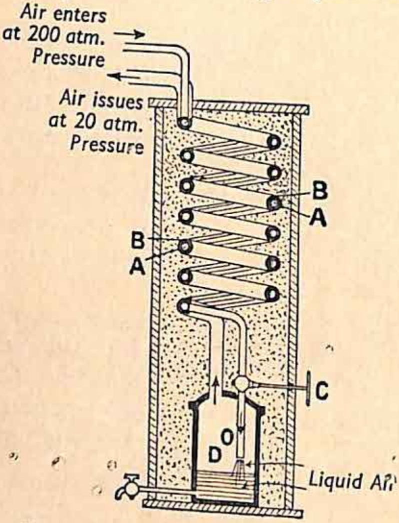
Air enters at 200 atm. Pressure
Air issues at 20 atm. Pressure
B
A
B
A
C
O
D
Liquid Air

FIG. 107.—Apparatus for liquefying air (diagrammatic)

The whole process is repeated and eventually a temperature is reached at which the air becomes liquid as it passes through the valve C.

### Liquid air

This substance, which is pale blue, can be kept for a short time in a vacuum flask. The temperature of liquid air is about − 190° C. The composition of liquid air is not the same as that of gaseous air; it consists of about equal weights of oxygen and nitrogen, and also contains argon, neon and very small quantities of other inactive gases.

### Manufacture of atmospheric gases

Since liquid air is a mixture of liquids which boil at different temperatures, it is possible to distil the liquid and obtain the separate gases. It is in this way that supplies of oxygen, nitrogen, argon and neon are obtained.

### Uses of argon and neon

The word "argon" is derived from a Greek word which means lazy. Argon is a gas which will not react with any other substance. It is used, mixed with some nitrogen, for filling gas-filled electric lamps. In a lamp of this type the wire can be made much hotter without vaporizing so easily as it did in the old-fashioned vacuum lamp; the filament thus gives a brighter light.

Neon is a very difficult gas to isolate, but very small quantities are used in "osglim" lamps and in the tubes of electric signs which give a red light. A discharge of electricity passing through the gas sealed in these tubes at a low pressure is responsible for the intense red glow. Neon discharge-tubes are employed on certain lighthouses as the red light penetrates fog.

## CHAPTER 16

# OXYGEN AND ITS CONNECTION WITH BURNING. NITROGEN

### The discovery of oxygen

Oxygen was discovered by an Englishman called Priestley and by a Swedish chemist called Scheele. Priestley obtained it by heating a substance which we now call mercuric oxide. The gas was not called oxygen at that time; Scheele gave it the name "fire-air" and he made it by heating several separate substances, one of which was nitre (potassium nitrate).

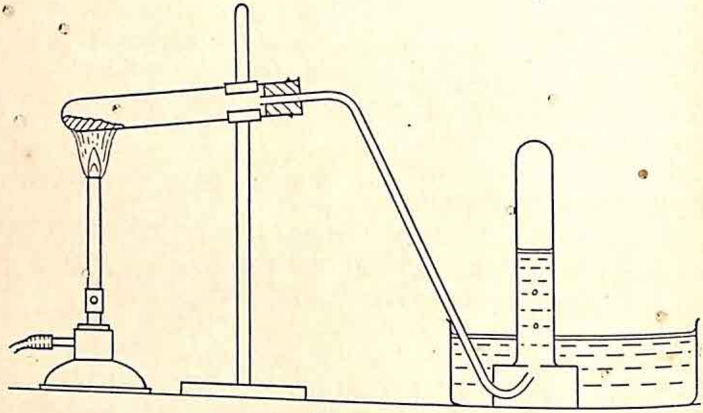

FIG. 108

EXPT.—*To prepare a little oxygen from mercuric oxide.*

Set up the apparatus shown in Fig. 108. Take about 2 gm. of red mercuric oxide (poisonous) and heat it in the hard-glass test-tube fitted with cork and delivery tube as shown. Note that the red solid becomes almost black. Allow the first few bubbles of gas which come out of the delivery tube to escape, then place a test-tube full of water over the hole in the bee-hive shelf and collect the gas till the tube is full. Close this tube with your thumb and remove the delivery tube from the trough. Now plunge a glowing splint into the oxygen; the wood will catch alight and burn brightly.

### How oxygen is made

Several compounds decompose when they are heated, giving oxygen as one of the products. Although mercuric oxide is not cheap and it does not give a good yield of the gas, the decomposition is very simple. If you examine the test-tube in which mercuric oxide was heated in the above experiment, you will see drops of mercury on the sides of the tube near its mouth. Some red solid will probably be left in the bottom of the tube; this is unchanged mercuric oxide. If you were to heat this solid long enough, it would all decompose into mercury and oxygen. The reaction is represented thus:

$$2HgO \rightarrow 2Hg + O_2.$$

Another simple method of obtaining a little oxygen is by the action of heat on red lead; this oxide of lead decomposes leaving a residue of the yellow oxide, thus:

$$2Pb_3O_4 \rightarrow 6PbO + O_2.$$

*Expt.* 4.—To obtain several jars of oxygen, the following method is commonly used. Some powdered potassium chlorate (approx. 15 gm.) is well mixed with some manganese dioxide[1] (approx. 5 gm.) in a mortar. The mixture is transferred to a boiling-tube, fitted with a gas-tight cork and delivery tube as shown in Fig. 109. The tube is heated *carefully* in order to obtain a steady stream of the gas. If the oxygen is liberated too rapidly, the flame must be removed till the evolution of gas

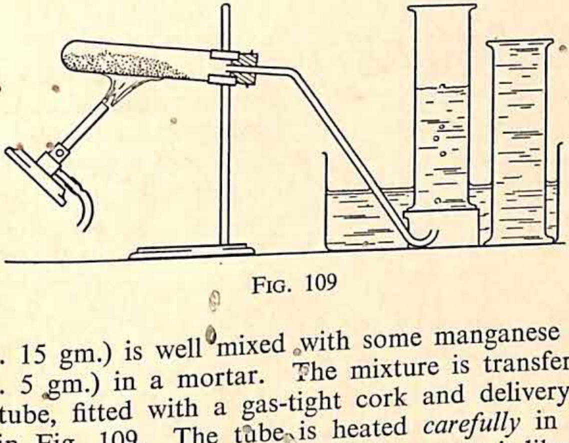

FIG. 109

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[1] It is advisable to roast the manganese dioxide in a dish, stirring with a glass rod, for some time to make sure that it is free from carbon.

slackens. For Expts. B–F, six 300 c.c. jars are collected as shown; as each jar is filled, it is closed with a greased glass plate and removed from the trough.

In this experiment the potassium chlorate ($KClO_3$) decomposes giving oxygen and potassium chloride ($KCl$), thus:

$$2KClO_3 \rightarrow 2KCl + 3O_2.$$

The manganese dioxide does not appear to play any part in the reaction, but in its presence the potassium chlorate decomposes much more easily on heating. The manganese dioxide in this reaction is called a **catalyst.**

Large quantities of oxygen are obtained from the air (see p. 137).

## The properties of oxygen

Oxygen is a colourless gas without smell.[1] It does not dissolve much in water, yet many aquatic animals can only breathe dissolved oxygen (p. 160). Oxygen is slightly denser than air.

With few exceptions animals and plants cannot live without free oxygen; the part which it plays in respiration is dealt with on p. 156.

Oxygen does not burn, but many substances burn in it readily, e.g. it rekindles a glowing splint.

The following experiments illustrate the readiness with which substances burn in oxygen. Note that the substances selected are elements. The jars of oxygen are prepared as in Expt. A, alternatively they can be obtained from a cylinder of the compressed gas.

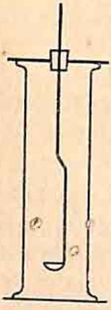

FIG. 110

*Expt. B.*—A piece of wood charcoal (essentially carbon) is heated till it glows in a deflagrating spoon, then lowered into a jar of oxygen (see Fig. 110). The carbon glows brightly for some time. (You may see a number of sparks, but these are due to an impurity in the carbon.) A colourless gas is left in the jar, and when a little lime-water is shaken with it, the liquid becomes milky. The gas formed is **carbon dioxide, $CO_2$.**

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[1] As prepared in Expt. A, the gas contains a little chlorine, but this can be removed by shaking a little caustic soda solution in a jar of the gas.

*Expt. C.*—When burning sulphur is lowered in another spoon into a jar of oxygen, the sulphur burns more brightly with a pale blue flame. The product is chiefly a colourless gas with a choking smell; it should be smelt cautiously. On shaking litmus solution with this gas, the litmus becomes red. The gas is **sulphur dioxide,** $SO_2$.

*Expt. D.*—A small piece of white phosphorus is just ignited in a spoon and quickly placed in a jar of oxygen; the phosphorus burns with extraordinary brilliance. In a dry jar of oxygen, a white solid, **phosphorus pentoxide,** $P_2O_5$, is formed; this solid is extremely soluble in water and is not seen if the gas jar is wet. The solution of phosphorus pentoxide in water causes litmus solution to become red.

*Expt. E.*—A coil of clean, thin iron wire (33-gauge) is made and suspended from a thick rod of copper or iron. The iron wire is made red-hot and quickly plunged into a jar of oxygen about one-third full of water (this prevents breakage of the jar if the product falls). The iron burns violently and emits a large number of sparks. The product is a blue-black solid, **magnetic iron oxide,** $Fe_3O_4$.

*Expt. F.*—A small piece of sodium[1] is heated in a clean spoon till the sodium burns, then the spoon is at once lowered into a jar of oxygen containing some water. The sodium burns with a bright yellow glow, and so much heat is given out that the spoon sometimes melts. The spoon is immersed in the water in the gas-jar and a piece of red litmus paper is dipped into the remaining liquid; the litmus becomes blue. The spoon contained some **sodium oxide,** $Na_2O$.

## How oxygen got its name

A solution which causes purple litmus to become red, usually contains an acid. You have noted that the oxides of sulphur and phosphorus give acid solutions in water. Lavoisier thought that all acids contained oxygen (this is not true), and that is why he gave it this particular name; the word "oxygen" means acid former.

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[1] Sodium is kept under rock-oil, as it is readily attacked by oxygen and by moisture; it must only be handled in filter-paper.

## The combination of elements with oxygen

Carbon, sulphur, phosphorus, iron and sodium are all elements; they each burn in oxygen. In each case, the only possible reaction is direct combination or joining together of the element with oxygen; the resulting compounds are oxides. **An oxide is a compound of oxygen with one other element.** You have already come across the ending *-ide* to the name of a compound (p. 67); it usually means that the compound consists of two elements. You can compare the names sodium chloride ($NaCl$), hydrogen sulphide ($H_2S$) and calcium carbide ($CaC_2$).

Almost all elements combine directly with oxygen; in addition to those mentioned above, magnesium burns violently in oxygen to form a white solid, magnesium oxide ($MgO$); copper if heated in a stream of oxygen forms a black solid, copper oxide ($CuO$); mercury at 300° C. slowly forms red mercuric oxide ($HgO$).

The term *oxidation* is applied to any chemical change in which oxygen combines with or reacts with a substance; the latter is said to be oxidized.

## Formulæ of oxides

You have been given the formulæ $CO_2$, $SO_2$, $P_2O_5$, $Fe_3O_4$, $Na_2O$, $MgO$, $CuO$, $HgO$. The only difficult one which has to be memorized is $Fe_3O_4$; the others you can construct, if your learn the **combining powers** or **valencies** of the elements. (See table, p. 211.)

## What do we mean by combining power?

Look at the following formulæ:

| | | | | |
|---|---|---|---|---|
| Hydrogen compounds . . | $HCl$ | $H_2O$ | $H_3N$ | $H_4C$ |
| Chlorine compounds . . | $HCl$ | $ZnCl_2$ | $FeCl_3$ | $CCl_4$ |

You see that:

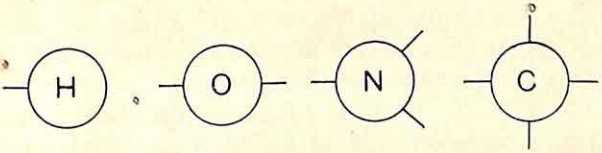
1 Cl combines with 1 H
1 O ,, ,, 2 H
1 N ,, ,, 3 H
1 C ,, ,, 4 H

We take the hydrogen atom as our standard, and the number of hydrogen atoms which combine with 1 atom of an element is the combining power of that element. Thus, the combining power of chlorine is 1, of oxygen 2, of nitrogen 3 and of carbon 4.

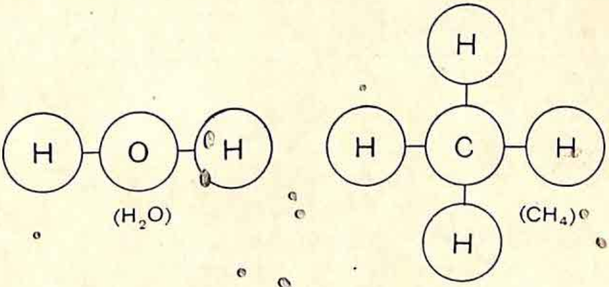
But many elements do not combine with hydrogen, e.g., zinc, copper and iron. Since the combining power of chlorine is 1, we find, in these cases, the number of chlorine atoms which combine with one atom of the element. Looking at the formulæ of the chlorine compounds above, you will see that the combining power of zinc is 2, of iron (ferric) 3 and of carbon 4 again.

## How to build simple formulæ

It is a convenient device to imagine that atoms have bonds attached to them, the number of bonds being the same as the combining power, thus:

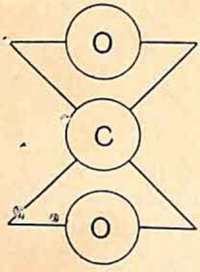


Further, that atoms when combined are linked by these bonds. Again, when the atoms have joined to form a compound there are no free bonds. Thus, we have:

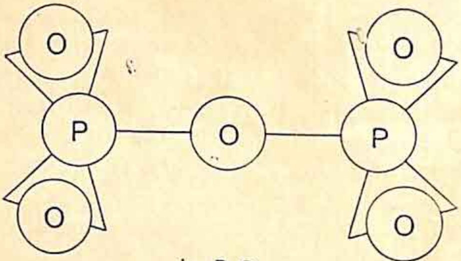


($H_2O$) ($CH_4$)

The combining power of oxygen is 2. What are the formulæ for carbon dioxide (note *di-* means 2) and phosphorus pentoxide (*penta-* means 5)? The combining power of phosphorus is 5.



i.e. $CO_2$



i.e. $P_2O_5$

This method of working out formulæ is rather laborious. Here is an alternative method.

Suppose the formula for phosphorus pentoxide is $P_aO_b$. Then, $a \times$ the combining power of phosphorus $= b \times$ the combining power of oxygen;

$$\text{i.e. } a \times 5 = b \times 2.$$

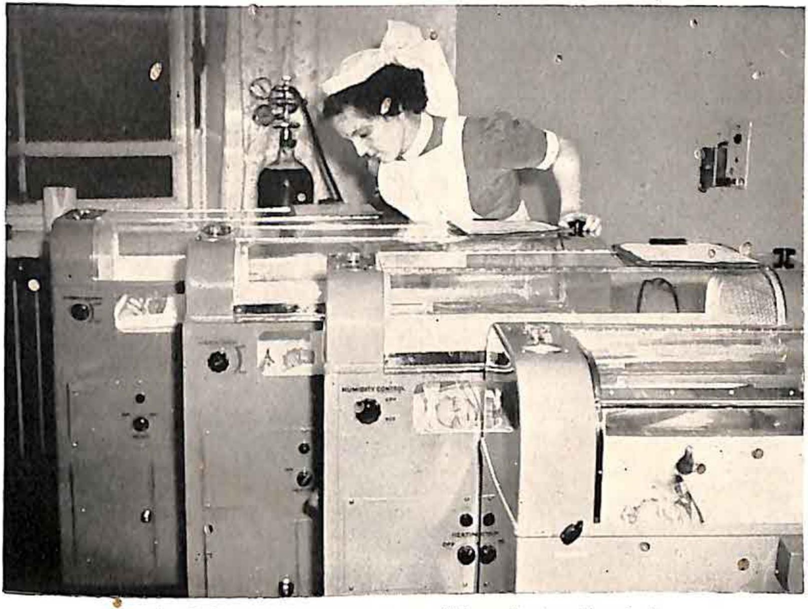
What are the simplest possible numbers we can substitute for $a$ and $b$ in this equation? Obviously, $a=2$ and $b=5$. The required formula is therefore $P_2O_5$.

This illustrates the method of finding most of the formulæ with which you need to be familiar. Combining powers are always simple numbers (2 is the commonest), and you should be able to work out formulæ mentally. Here are some examples:

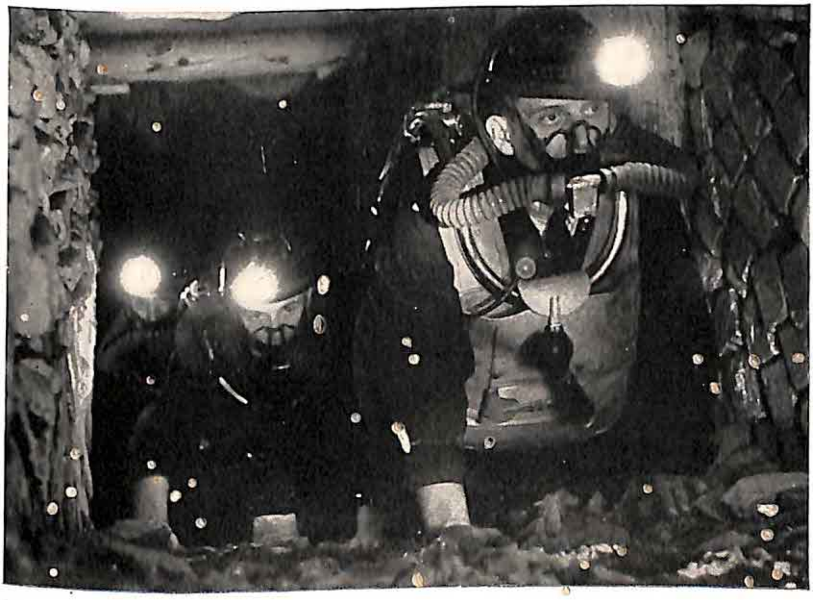
| Combining power of element E . | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Formula of oxide of E . . . | $E_2O$ | $EO$ | $E_2O_3$ | $EO_2$ | $E_2O_5$ |
| Actual examples . . . . | $H_2O$<br>$Na_2O$ | $CuO$<br>$ZnO$ | $Fe_2O_3$ | $CO_2$ | $P_2O_5$ |

## Matches

A box of about fifty matches can be bought for twopence to-day. The first friction matches, invented in 1826, were not nearly so good, but they were sold for twelve a penny. Matches are extremely useful, but few people know anything of the varied processes employed in their production. The making of matchsticks from logs of wood is very interesting and it is fascinating



A. Babies in oxygen-tents at Westminster Hospital



B. Team equipped with mine rescue apparatus crawling along roadway (see p. 148)

A. Oxy-hydrogen underwater cutting

B. Oxy-acetylene welding (see p. 149)

to watch a machine, which holds about a million sticks in a long band, applying a little wax, dipping the sticks in the mixture of chemicals to form the head, drying the same, counting and putting the matches into boxes.

We must confine ourselves to the simple chemistry of the lighting and burning of matches. Nowadays, there are two kinds of matches, strike-anywhere and "safety" matches. The head of a friction or strike-anywhere match contains several substances, but it consists essentially of a mixture of a compound of phosphorus and sulphur, potassium chlorate with some binding material, e.g. glue, and some kind of dye. It is a curious fact that matches of a special colour are demanded in certain districts; except for the colour, all the matches of this type are the same. At ordinary temperatures, the above mixture is quite stable, but by drawing the head of the match across a rough surface, e.g. a piece of sand-paper, heat is produced locally by the friction and a violent chemical action begins. The compound potassium chlorate contains about 40 per cent of oxygen by weight; with this oxygen, the phosphorus and sulphur in the phosphorus sulphide combine to form the oxides of phosphorus and sulphur; sulphur dioxide is easily recognized by its smell. In the production of these oxides, much heat is set free, so that the wax on the stick and the wood catch alight in turn.

In the case of "safety" matches, the heads consist essentially of potassium chlorate, some slow-burning substance, e.g. antimony sulphide ($Sb_2S_3$), colouring matter and a binding material. There is no phosphorus in the head of the match, but the coating on the box contains red phosphorus. "Safety" matches can be struck on glass or linoleum, but they ignite very easily on the box-coating. You will see that a little coating disappears from the box each time a match is struck; presumably what happens is that by rubbing, a little red phosphorus and some of the potassium chlorate in the match-head are caused to react. This reaction raises the temperature of the substances in the match-head, so that they react much in the same way as the substances in the head of a friction match.

*You should on no account attempt to make matches.* Potassium chlorate is a very dangerous chemical when mixed with certain other substances. Careless people are not unknown who have been seriously burnt through having loose throat-tablets of potassium chlorate in the same pocket as a box of "safety" matches. Can you explain why?

## The production of heat in chemical reactions

When chemical changes take place, heat is generally given out, often light as well; such reactions are examples of **combustion** or burning. The production of fire and the use of the heat liberatod is of great importance in ordinary life. In Britain about 40 million tons of coal a year are burnt in domestic fires; the oxidation of coal by atmospheric oxygen provides the necessary heat to keep our houses at a comfortable temperature and in many cases to cook our food. To-day, in many homes coal-gas is burnt for either or both of these purposes. Again, coal or certain oils are burnt to heat water and produce steam under pressure for driving engines of various types. We may use these engines to move from one place to another, e.g. on a train or ship, to drive machinery for innumerable manufacturing operations, or to drive generators for the production of electrical power.

The burning of coal-gas, petrol vapour and the vapour of certain oils, under particular conditions is explosive. The force of this explosive burning is employed to drive the varied types of internal combustion engine. You are all familiar with cars, aeroplanes, tanks and tractors, and should realize that their movement depends in the first place upon a chemical reaction.

In most reactions which we use for producing heat, oxygen, either free or combined, plays a part. We have already seen that combined oxygen reacts with phosphorus and sulphur in the lighting of a match. Coal is a complex form of matter, but about 80 per cent is carbon. The heat obtained by burning coal is chiefly that produced in the union of carbon and oxygen to form carbon dioxide.

## How do we put out fires?

To put out a fire we must try to keep air away from the burning substance. If the fire is small, we can do this by covering the burning material with some kind of matter which does not burn, e.g. sand, earth or water. Water as well as excluding air has a considerable cooling effect (p. 175). Fire-extinguishers on motor cars contain a liquid which, when sprayed on to the fire, produces a covering of dense vapour. Extinguishers generally found in schools produce a jet of liquid which is giving off carbon dioxide. The liquid acts in the same way as water, while the carbon dioxide, being dense, tends to smother the fire. A soda-water siphon for a very small fire would be a good substitute. Burning clothing can be extinguished by rolling on the ground, or better still, by wrapping the victim in a blanket or rug.

## Burning of carbon compounds

Wood, paper, starch and sugar do not look alike, but they do resemble each other in being composed essentially of the elements carbon, oxygen and hydrogen.[1] You probably know that most of our paper is made from wood, and everyone knows that both substances burn. When paper is burnt incompletely, a black substance is left, and you must have seen pieces of charred wood (charcoal) in the remains of a bonfire. The black substance is carbon. Similarly, if you heat starch or sugar in a closed crucible for some time, you will find a black residue, carbon, in the crucible.

When free carbon is burnt it produces carbon dioxide. When a carbon compound is completely burnt, i.e. in a plentiful supply of air, or oxygen, the carbon appears in the products as carbon dioxide.

You have learned (p. 117) that the element hydrogen burns; while burning, it combines with oxygen to form water. When a hydrogen compound burns, in excess of air or oxygen, the hydrogen in the compound is converted into water (hydrogen oxide).

When compounds of carbon and hydrogen, e.g. the compounds in petrol, are completely burnt in air, the products are carbon dioxide and water. The same products are obtained by burning compounds of carbon, hydrogen and oxygen, e.g. wood, sugar and fats, only in these cases the oxygen present in the compounds assists in the formation of the two oxides.

You know that heat is given out when wood and paper burn.

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[1] Starch and sugar are **carbohydrates**; they contain hydrogen and oxygen atoms in the ratio of 2 : 1 (cf. water). The formula of cane sugar is $C_{12}H_{22}O_{11}$.

Similarly, heat is produced when a lump of burning sugar is lowered into a jar of oxygen. It is the slow-burning or oxidation of compounds of carbon, hydrogen and oxygen, by oxygen in the cells of our bodies, which keeps us warm (see p. 156).

## Use of oxygen medicinally

Either atmospheric oxygen, i.e. oxygen diluted with nitrogen, or oxygen dissolved in water is adequate for the breathing of most animals. There are, however, certain lung-diseases in which it is necessary to provide the patient with air richer in oxygen than ordinary air. This is effected by enclosing the patient in a special kind of tent, oxygen being fed into the tent from cylinders of the compressed gas. See Plate VII A.

## High-altitude climbing and flying

The higher we ascend into the atmosphere, the "thinner" the air becomes; the pressure diminishes and the gases are less dense. Our lungs have the same volume, so that when we inhale, we do not take in as much oxygen at the top of a mountain as we do at sea-level. In climbing very high mountains, like Mt. Everest, this lack of oxygen makes progress very slow. Climbers have overcome this difficulty by carrying small cylinders of compressed oxygen fitted to a special mask. Similar measures are used in flying to great heights.

## Mine-disasters

Explosions in coal mines unfortunately still occur. No matter whether the explosion is due to coal-dust or fire-damp (methane), the gases left after the explosion contain little or no oxygen. The men in rescue parties are provided with special equipment by means of which they obtain a supply of oxygen from cylinders strapped on their backs. Firemen, too, often have to venture into atmospheres devoid of oxygen, in which case similar respirators have to be worn.

## Welding and cutting

Atmospheric oxygen is usually sufficient for ordinary burning, especially if a draught is used, e.g. in an engine fire-box. Pure oxygen would cause substances to burn too easily. Oxygen is employed to burn coal-gas, hydrogen and acetylene in special burners, in order to produce flames with very high temperatures. It is easy to show that an oxy-coal-gas flame will burn a knitting needle in two. This same kind of flame causes a lump of lime to emit a very bright light; this lime-light was used not very long ago as the source of light in lanterns. With an oxy-coal-gas blowpipe it is possible to work the harder types of glass which are now being made.

The oxy-acetylene flame has a temperature of about 3300° C. It is used for welding, i.e. joining together, pieces of iron, and in conjunction with an oxygen-jet for cutting iron. An oxy-acetylene flame is first used to heat the metal at one point, then the oxygen-jet is allowed to play on the heated iron. This oxygen burns out some of the iron as iron oxide ($Fe_3O_4$); in this way it is possible to cut iron several inches thick. Once the operation has been started the burner can be used to cut out pieces of metal of any desired shape on special machines. See Plate VIC.

## To obtain nitrogen from the air in the laboratory

*Expt. G.*—Roughly 80 per cent of the air by volume is nitrogen, and, neglecting the minor constituents, it is only necessary to remove the oxygen from air to obtain nitrogen. This is done by

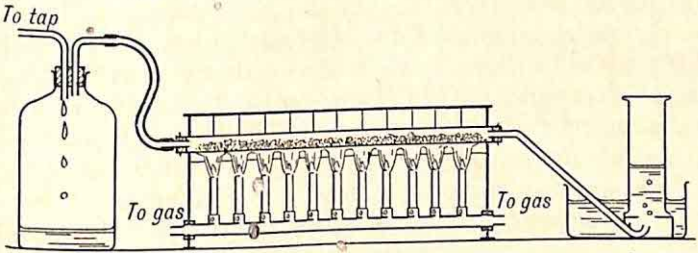

FIG. 111

passing a slow stream of air through an iron tube packed with copper turnings, the tube being kept red-hot. Suitable apparatus is shown in Fig. 111. Water from the tap, dripping into the large bottle, displaces air, which passes through the iron tube and over the copper. The copper combines with the oxygen to form copper oxide, while the nitrogen passes on and is collected over water.

## The properties of nitrogen

Nitrogen is a colourless gas, which has no smell. It is even less soluble in water than oxygen, and its density is a little less than that of air.

Nitrogen does not burn, and ordinary combustibles do not burn in it. If magnesium is heated in nitrogen, the two elements combine slowly to form magnesium nitride, $Mg_3N_2$ (magnesium cannot be used in preparing nitrogen from air).

The element nitrogen seems to be inactive, but it is possible to get it to combine with some elements under special conditions. Thus, it will combine with hydrogen to form ammonia, $NH_3$; with difficulty it will combine with oxygen.

## Nitrogen and life

Nitrogen appears to be dull stuff; it is not easy to do anything spectacular with it. Nevertheless, it is an important element, without which plants and animals cannot live. With the exception of one class, viz. that which includes peas, beans, clover and lupins, plants cannot use free nitrogen. Most plants and animals must be supplied with nitrogen compounds in their food. The **plants require nitrates** which they obtain in dilute solution from the soil. Nitrogen in the form of nitrates, however, is useless to animals. **The food of animals must contain** rather complex compounds of carbon, oxygen, hydrogen and nitrogen which are called **proteins.** These substances are built up by living things and we obtain our supplies from plants or other animals. Examples of protein foods are gluten in flour, white of egg (albumen), the curdy matter in milk (casein), fish and lean meat.

## CHAPTER 17

# BLOOD

### The blood of a frog

Like our own blood, that of a frog seems to be a red-coloured liquid. We shall put a drop of it on a microscope slide and examine it through a microscope. As a very thin layer is necessary, we just touch a drop of the blood with a cover slip, put another cover slip so that the blood spreads out between them, and then draw the two apart, waving them in the air till they are dry. When we look at this very thin layer through the microscope ($\frac{1}{3}$-in. or $\frac{1}{6}$-in. objective), the red colour has gone. Instead we can see an enormous number of small, separate, yellowish-coloured bodies called **corpuscles.** It is these that cause the red appearance, since that is their colour when seen in any but very thin layers. The frog's blood is made up of a very pale yellow liquid with these corpuscles floating in it.

If it is spring, and we can get a tadpole, the corpuscles are better seen in the living animal. We choose a tadpole with well marked external gills, or alternatively with a thin, not too opaque tail, and place it in a 1 per cent aqueous solution of urethane until it is anæsthetized. It is then examined under a microscope. When we have the thinner parts of its gills or tail in focus we gently move the slide till we pick out a suitable blood vessel. The scene now is quite a lively one, and we can see the corpuscles rushing along and dividing into different streams at the junction of two blood-vessels. The flow in any one vessel is always in the same direction, showing us that the blood must be in some sort of **circulation.**

### The circulation of the blood in the frog (simplified)

The organ which causes the blood to circulate (i.e. pass round the body) is the heart. The frog's heart (Fig. 112) consists of three main chambers, two of which receive blood as it enters the heart. These are called the **auricles,** one being on the left side and the other on the right. After the blood has entered these it passes to the third chamber, the **ventricle.** This is the real pump which keeps the blood moving round the body. When it has filled with the blood received from the auricles, it suddenly contracts, thus forcing the blood out of the heart. An arrangement of valves prevents it from going back into the auricles. Instead, it passes out to the **arteries,** the blood-vessels which carry blood away from the heart. In these some goes to the lungs and skin, while all other parts of the body receive some of the rest. When they reach a part of the body to which they are supplying blood, the arteries divide into an enormous number of very thin-walled, very narrow blood-vessels called **capillaries.** As they leave that part, the capillaries reunite to form larger blood-vessels called **veins.** The veins then carry the blood back to the heart, where it re-enters the auricles and then passes to the ventricle. Thus the ventricle is the main blood-pump. It exerts the necessary force to send the blood right through the arteries, capillaries and veins, and back to the heart again. The auricles receive it and pump it to the ventricle.

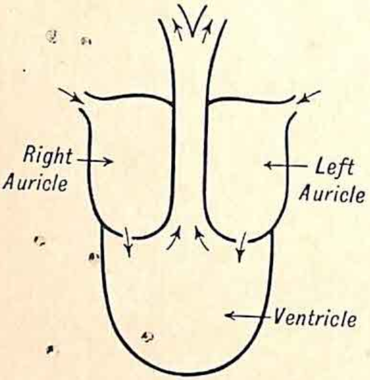

FIG. 112.—Frog's heart (diagrammatic)

Near the pump, that is in the arteries, the force is greatest. The arteries therefore must have strong walls. They also have elastic walls that can "give" a little when the force from the pump is greatest, and return to normal size again afterwards. The capillaries have the thinnest walls of all, since it is through them that the parts of the body exchange materials with blood. The veins have thinner walls than the arteries, but are slightly wider tubes (Fig. 113).

## Our own blood

Let us examine a drop of our own blood on a slide, in the way we used for frog's blood. The red corpuscles are again the most noticeable feature. There are far more of them than in the frog, but they are smaller and they have no nucleus (Fig. 114). A living cell, like these corpuscles, which has no nucleus is unusual. It is obvious that they are very small, since they look minute, even under quite high magnification. There are about five million of them in each cubic millimetre of blood. As there are about five million cubic millimetres of blood in a man's body their total number is enormous. Two drops of blood would contain more red corpuscles than there are human beings in Europe.

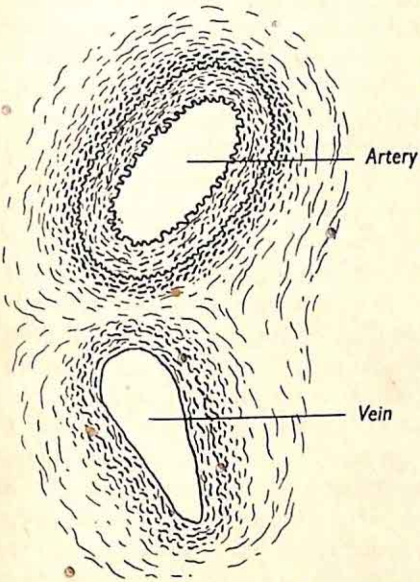

FIG. 113.—Section through an artery and a vein

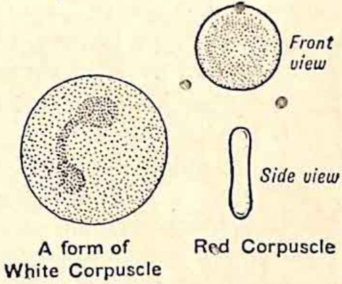

FIG. 114.—Blood corpuscles

Besides the red corpuscles we may be able to find a few of another kind. These are the **white corpuscles.** There is only one of them to about five hundred of the red ones.

The liquid in which these corpuscles float is called the **plasma.** It contains many dissolved substances, such as salts, oxygen, carbon dioxide and circulating food materials.

## How our blood circulates

As in the frog, our blood circulates through a series of arteries, capillaries and veins, and is pumped round the body by the heart. The heart of man, and of all mammals, differs from that of the frog, since it is divided into two entirely distinct halves by a partition down the middle. Each half has its own **auricle** which receives blood from the veins and passes it to its **ventricle.** The ventricle then contracts and pumps the blood to the arteries. There are thus two ventricles and two auricles. The right ventricle circulates the blood to the lungs, after which it returns to the left side of the heart. The left ventricle pumps it round the arteries, capillaries and veins of the whole of the rest of the body. The left ventricle thus has a very big task to perform, and it is the most muscular part of the whole heart (Fig. 115). (See also Appendix C, p. 213.)

A little more should be said about the capillaries. Since all the exchanges take place in them, they are the really important part of the circulatory system. Each capillary is not only a very narrow tube; it is a very short one. There is a very large number of them. A distinguished biologist has calculated that the capillaries in a man's body have a total area of about 6,500 sq. yd., and that their lengths, end to end, would stretch two and a half times round the world. All this means that there is a very big area over which materials are being exchanged between the blood and the other parts of the body.

Most of you know that in certain circumstances a cut from which bleeding takes place may be very dangerous. If a cut is deep it may penetrate an artery. The blood then rushes out in a very jerky, forcible manner, corresponding to the pumping movements of the heart. It is necessary to stop the bleeding quickly or a serious loss of blood will follow. The usual method is to compress the artery between the cut and the heart, so that no more blood can flow into the cut part. A deep wound may also cut a vein. In this case the blood gushes out quickly but smoothly since the jerky flow due to the heart pump is lost in the capillaries. To stop bleeding in a vein, the vein is compressed on the side away from the heart, because blood in the veins is flowing back towards the heart. An arrangement of valves is present in the veins which prevents blood from flowing back in the wrong direction. A small scratch, which only bleeds for a short time, has merely cut into the capillaries.

## How the blood is connected with our breathing

We are warm-blooded, and need a good deal of heat to keep up our temperature. Even if we were cold-blooded, we should still require much energy to enable us to carry out all our movements, and to do the work necessary to keep all our parts working. From where does this energy come? You already know that a motor car burns petrol (p. 147), and it uses the hot gases so obtained to drive the engine and so move the car. We get heat in a way which is very similar to this in many respects. Instead of petrol, some of the food we eat is carried in an altered form to the various parts of the body and there stored up. As these parts carry out their normal duties, they slowly oxidize these stored foods to get the heat which enables them to keep working. For the oxidation, oxygen is needed, and this is brought along in the blood from the lungs. When a good athlete is running hard, he may be using as much as 4000 c.c. in a minute.

When you studied oxygen, you collected the gas by bubbling it through water in a gas jar. Evidently it does not dissolve very readily in water. If the blood had to carry oxygen which was merely dissolved in the liquid of the blood, the heart would have to pump nearly 5 gallons of blood every second when a man was working hard. No heart could do this, so a special method has been adopted by the body to allow a fixed amount of blood to carry an increased quantity of oxygen. The red corpuscles contain a substance called **hæmoglobin.** It is purplish-coloured, but when it is exposed to the air, as in the lungs, it takes up oxygen and turns to a bright red substance called oxy-hæmoglobin.

$$\underset{\text{(purple)}}{\text{Hæmoglobin}} + \text{oxygen} \rightarrow \underset{\text{(red)}}{\text{oxy-hæmoglobin}}.$$

When this compound reaches a part of the body which needs oxygen, it gives up its oxygen and turns back to hæmoglobin.

One reason for the circulation of the blood is now quite clear. It enables oxygen to be taken from the lungs to the parts where it is needed. Another is this: the material which is oxidized is a compound of carbon, hydrogen and oxygen; when it oxidizes, carbon dioxide and water are formed (p. 147). The carbon dioxide dissolves in the blood and is carried round till the blood comes to the lungs. There it escapes into the air together with some water vapour. Thus the air we breathe out contains less oxygen and more carbon dioxide than the air we breathe in.

We can now follow the circulation in a little more detail (Fig. 115). Blood rich in oxygen has just entered the left side of the heart. It is received by the left auricle which forces it into the left ventricle. The left ventricle contracts and forces the blood

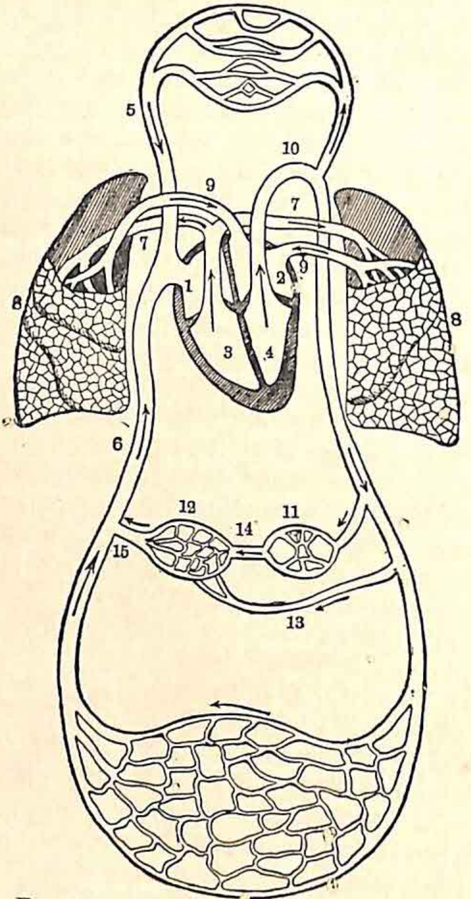

FIG. 115.—The circulation of blood in man

1, right auricle; 2, left auricle; 3, right ventricle; 4, left ventricle; 5 and 6, the great veins (venæ cavæ) which bring blood back to heart; 7, arteries to lungs; 8, lungs; 9, veins from lungs; 10 aorta; 11, stomach and intestines; 12, liver; 13, artery to liver; 14, portal vein from intestine to liver; 15, vein from liver.

out into the largest artery, the **aorta.** There are valves between the ventricle and the auricle which prevent the blood from going back into the auricle, and again at the entrance to the aorta, which prevent the blood from going back into the ventricle when the contraction is over (Fig. 153, p. 214). The aorta branches into the various arteries which carry blood to all parts of the body. The actual exchanges of oxygen and carbon dioxide take place through the thin walls of the very narrow capillaries which branch from the smallest arteries. Oxygen is given to the parts which need it, while carbon dioxide enters the blood. The blood, now purple-coloured owing to loss of oxygen, returns in the veins to the right side of the heart and enters the right auricle. The auricle contracts, forcing it into the ventricle, and the ventricle contracts, forcing it into the artery which leads to the lungs, the **pulmonary artery.** In the capillaries of the lungs it loses carbon dioxide, gains oxygen and becomes bright red again. It now returns by the **pulmonary vein** to the left auricle and the process is repeated. You should note one fact about the circulation between the lungs and the heart. The pulmonary artery, unlike all the other arteries, carries blood which has lost its oxygen, while the pulmonary vein carries blood which is rich in oxygen. The fact that the blood receives oxygen in the lung-capillaries, but loses it in capillaries in other parts, is responsible for this.

### Other duties of the blood

The liquid of the blood, in which the corpuscles float, is called the **plasma,** and it has several important functions. If you prick yourself, the bleeding soon stops because a **clot** forms and blocks the hole. The clot is formed from substances dissolved in the plasma. When the blood comes in contact with a damaged part, such as the edge of a cut, these substances form a network of fibres which entangles the corpuscles, blocks the cut, and stops the bleeding. In a large cut the blood flows too quickly for the hole to be blocked, so we slow it down by putting a pad over the wound, or by compressing the artery or vein which is bleeding. For treatment of various diseases, it is often useful to have some of the blood plasma from which these fibres have been removed. This is called **serum.** Serum is blood from which the corpuscles and the fibre-forming substance have been removed.

The plasma also carries digested food to its destinations in the body, and it carries waste materials from the parts where they are formed to the parts where they can be removed from the body.

**Chemical messengers** are also carried in the plasma. When partly digested food leaves the stomach and enters the intestine, it needs a liquid produced by the pancreas to continue the digestion. A chemical is passed into the blood from the wall of the intestine: it circulates to various parts of the body, but its effects are chiefly on the pancreas. When the chemical reaches the pancreas, that organ produces the necessary liquid and sends it along to the intestine.

**Blood is our defence against disease.** You will remember the white corpuscles, which were so much outnumbered by the red ones (p. 153). They are the policemen of the body, or perhaps we should think of them as our defensive army. Many diseases are caused by minute organisms called **germs** or microbes. Biologists call them **bacteria.** They get into our body chiefly through the mouth and through small cuts in the skin. When this happens, the white corpuscles swarm round the invading bacteria and try to get rid of them by eating them in the same sort of way that Amœba eats its food.

The damage done by bacteria is usually due to small quantities of poisonous substances called **toxins** which they produce. The body tries to counteract their effects by making substances known as **antitoxins.** You have all heard of vaccination. To combat smallpox, antitoxins are produced as follows. There is a very similar disease of cows called cowpox, which is comparatively harmless to human beings. A few cowpox germs are injected into a person's blood, giving him a mild attack of this non-infectious disease. The body makes a large excess of antitoxins, and when the slight attack of cowpox is over, the person is found to be immune, not only to cowpox, but to smallpox as well. Typhoid fever and rabies (a disease due to bites from a mad dog) are treated by methods which are somewhat similar to this, but the methods differ in certain details.

Sometimes, when germs have already attacked a person, it is too late to protect by vaccination. In that case it is necessary to inject the antitoxins themselves. Diseases treated like this include diphtheria and tetanus (lock-jaw). A horse may be made immune to tetanus by giving it small doses of tetanus toxin. Its blood then gets a large excess of tetanus antitoxin. Some of the blood serum of the horse can then be injected directly into the blood of the sufferer, thus providing him with the antitoxin he needs. Provided this is done soon enough, he is then safeguarded from the effects of the disease. This treatment is now carried out on all wounded soldiers, to safeguard them in case tetanus germs have entered their wounds. Civilians wounded in air raids were also treated in this way.

## Blood transfusion

Centuries ago men, believing that it had magical properties, sometimes passed blood directly into the veins of dying people, often with unaccountably harmful results. We now recognize different blood types or groups, and know that mixing of certain groups is safe but that mixing of other groups may be harmful and even fatal to the receiver. We can test for the different groups fairly simply, so that it is possible to transfer the right kind of blood from one person to another with every confidence.

Though blood can be transferred directly from person to person it is usually drawn, by an almost painless process, from a vein in the arm into a bottle containing a solution to prevent clotting. The mixture can be stored for a limited time until it is needed. Often, however, the corpuscles are removed and the plasma evaporated by special methods to a dry solid. This keeps indefinitely and can be carried about anywhere. When sterile water is added plasma is reformed. For the treatment of serious burns, such as sometimes occur in air crashes, this regenerated plasma is even better than whole blood. Thousands of lives have been saved by the use of whole blood or plasma following serious wounds or accidents, and during certain illnesses.

## CHAPTER 18

# THE RESPIRATION OF ANIMALS AND PLANTS

Both animals and plants require oxygen, use it, and give out carbon dioxide (p. 140). The exchanges of oxygen and carbon dioxide in living matter are called **respiration**. Breathing is just part of the process of respiration, which also includes the changes which occur with these gases in all parts of the plant or animal. We will now consider the process of breathing in a few typical kinds of animals.

**Amœba** takes in oxygen all over its surface (see p. 76), and gives out much of its carbon dioxide in the same manner. It also loses some of its carbon dioxide in the water squirted out by the contractile vacuole. It has no liquid which we could compare to the blood.

An **insect** breathes by means of tubes which lead from parts of its exterior to all the inner living parts. A house-fly, for instance, has nine pairs of openings on its body, from which branching air-tubes, or tracheæ, run to all parts of the body. Movements of the body pump air into the inner parts and then pump it out again. This gives a very efficient oxygen supply. The blood of an insect has no connection with its respiration.

In an **earthworm** there is blood which contains hæmoglobin, but there are no red corpuscles. The hæmoglobin is merely dissolved in the blood plasma (p. 153), which is a clear red liquid. In the course of its circulation the blood passes through capillaries in the skin. Oxygen, from the air dissolved in the moisture on the skin, is absorbed by the hæmoglobin, and is carried to the various parts. Carbon dioxide is brought in solution and passes out to the air through the skin.

**Fishes** obtain oxygen by means of gills. If you examine a fish such as a herring or a mackerel, you can see the gills quite plainly. The fish takes in water by its mouth as it swims along, and passes it out again through slits which open from the back parts of the mouth to the sides of the body. As the water containing *dissolved* oxygen goes through these gill-slits, it passes over the gills. These are parts where a good supply of blood is only separated from the water by a very thin membrane or covering. Oxygen passes into the blood here, and carbon dioxide passes out into the water. You should note that it is only dissolved oxygen that is any use. Gills do *not* enable fish to use the oxygen that is combined with hydrogen in the water. The carbon dioxide in the water from the gills is shown by the use of a special substance called aurin, which changes from a red to a yellow colour in the presence of even small quantities of this gas.

*Expt. A.*—A parallel-sided glass trough is taken, with a block of glass in the bottom which occupies about half the width of the trough. It is rinsed out with distilled water and filled to a depth of 1–1½ in. above the block. Aurin is added to give a distinct coloration and then, if necessary, sufficient lime-water, a drop at a time, to turn the colour to a permanent pink. The trough is arranged in a projection lantern, focused approximately, and a fish put in (a goldfish is suitable) which is of such a size that it cannot easily turn round in the trough. If the fish is now focused accurately and left undisturbed, periodical quiet intervals occur during which the water round the gill-slits turns to the acid colour, yellow, owing to the dissolved carbon dioxide expelled from the gills. The block of glass serves to keep the fish off the bottom of the trough and shows the change more clearly. (The stock solution of aurin contains 0·6 gm. of aurin (rosolic acid) dissolved in 100 c.c. of 50 per cent alcohol.)

## Frogs

If you place a frog where you can watch it closely, you will see that the bottom of its mouth seems to consist of very loose skin which is moving up and down quite quickly. If the frog is at all excited, as it may well be if you have just handled it, this movement may be even quicker than normal. While it is taking place the mouth is closed, but the nostrils remain open. As a result air is passing into and out of the mouth. Inside, the air gives up oxygen to the blood capillaries in the mouth of the frog, and a good deal of the frog's oxygen is obtained in this way. Now and again, there is a closing of the nostrils followed by a gulp in which some of the air in the mouth is forced into the lungs of the frog.

These are two elastic bags, whose surfaces are much folded, and they have a good supply of blood capillaries. The oxygen from the air, which has been gulped in, dissolves in the blood in the capillaries. In addition to these two methods a frog constantly obtains oxygen through its moist skin. This is an important method to the frog, and if its skin gets dry the frog may die. When an adult frog is under water it breathes by its skin only.

## Respiration in ourselves. Our lungs and chest

Imagine two bunches of grapes, with a short stem to each bunch, hanging from a longer stem. If the stems were hollow tubes and the grapes very thin-walled, hollow air-sacs, you would have a fair model of what our lungs are like (Fig. 116). The long stem corresponds to our windpipe, the grapes to the final small air pockets in which the exchange of gases takes place. In between them are the numerous branchings of the windpipe. It divides first into two, then again and again until there is a separate little tube going to each air-sac (Fig. 117). All the little

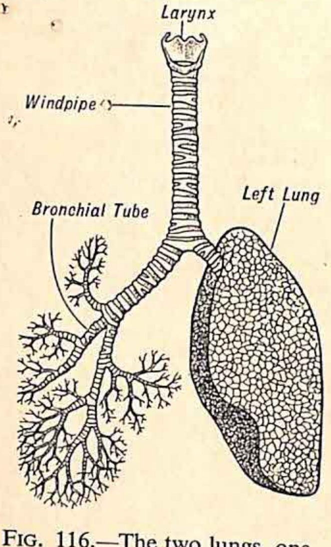

FIG. 116.—The two lungs, one dissected to show the air tubes

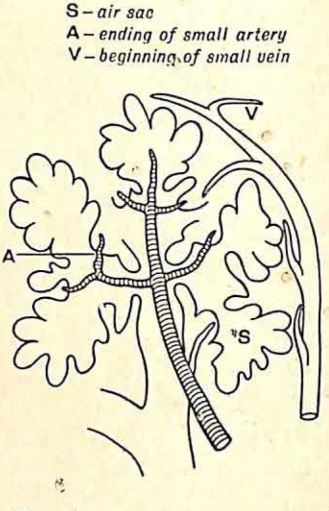

FIG. 117.—Diagram of part of a lung

air-sacs have a good supply of blood capillaries. The lungs themselves are enclosed in a double bag or membrane, called the **pleura.** This double membrane, with a little liquid between its two layers, allows a free gliding movement while you breathe, and in this way prevents the lungs from chafing on the chest wall. In the illness called pleurisy the pleura becomes inflamed, and the two layers may stick together in places, thus causing much pain as you breathe.

The chest itself is a closed box. The top and sides of this box are formed by the bones and muscles of the chest. At the bottom it is closed by a big sheet of muscle, called the **diaphragm,** which is in the shape of a dome. There is no way from the inside of the chest to the outer air, except that from the inside of the lungs, through the windpipe, to the nose and mouth.

### How we breathe

Place one hand on the body against the stomach, and breathe in and out, normally at first, then more deeply. You will note that when you breathe in, the stomach moves **outwards.** The dome of muscle forming the diaphragm has contracted and become flatter in shape. This forces the stomach outwards, but, what is more important to us, it makes the chest bigger.

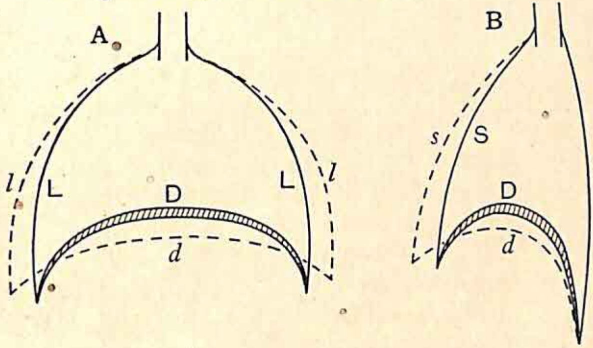

FIG. 118.—Diagrams to show enlargement of chest during inspiration
A, *vertical section, front view.*
B, *vertical section, side view.*
D, *d*, diaphragm; L, *l*, side walls of chest; S, *s*, sternum (breast bone.)

Now hold your hands on the sides and front of the chest while you are breathing. As you breathe in deeply the sides push outwards, and the front forwards. These movements also make the chest bigger.

Thus to breathe in, the muscles of the chest move the ribs so that the chest walls move outwards, while the diaphragm muscle contracts and pulls the bottom of the chest downwards (Fig. 118). Fig. 119 shows a model which illustrates the action of the diaphragm. When the sheet of rubber at the bottom of the bell-jar is pulled downwards, it increases the volume of the jar, and the balloon becomes a little larger. When the chest expands the pressure of the atmosphere similarly forces air down the wind-pipe into the lungs, so that they still fill the chest cavity (a point of difference from the model). After a pause the muscles relax. The diaphragm resumes its dome-like shape, and the weight of the ribs causes them to fall back into their original position. All this makes the chest smaller again and gases are forced out of the lungs. In other words, we breathe out. The lungs, of course, are never empty. After a man has breathed out there are about 2500 c.c. of gases left in his lungs. He breathes in and out about 500 c.c. in each normal breathing movement, but the amount may be very largely increased, if he is taking exercise or breathing deeply for any other reason. In any case a steady exchange of gases is taking place between the blood and the air-sacs of the lungs. The air we breathe in has about 21 per cent of oxygen in it, and only about 0·04 per cent of carbon dioxide. When the gases leave the lungs the proportion of oxygen has fallen to about 16·5 per cent while the carbon dioxide has risen to 4 per cent. For these changes to take place in the short time of one breathing movement a big area of lung is needed. Owing to their peculiar structure the internal area of the surface of the lungs is as much as 100 times the area of the skin on the body.

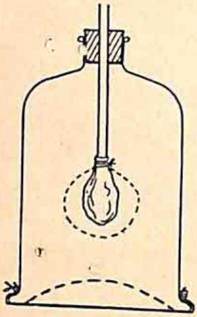

FIG. 119

You will have noticed by now the close connection between the blood and respiration. In the frog, and in ourselves, the objects of respiration are to get oxygen into the blood and carbon dioxide out of the blood. When the oxygen has got into the blood, it is carried round the body to all the parts that need it, i.e. to all the living cells in the body.

A very simple experiment shows the formation of carbon dioxide during respiration. You breathe in through the ⊥-piece of the apparatus shown in Fig. 120. Air enters by bubbling through the lime-water of tube 1. When you breathe out, the gases pass through the lime-water in tube 2. After a minute or two of breathing through this apparatus, the lime-water in tube 2 turns milky while that in the first tube is unchanged. Since carbon dioxide is the gas which turns lime-water milky, it follows that your body has produced some of this gas and passed it out with the gases you breathed out. The following experiment shows a similar effect caused by the breathing of a mouse.

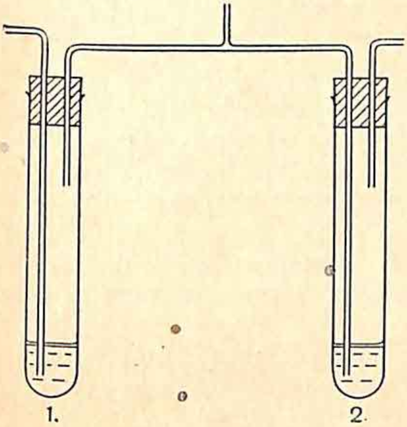

FIG. 120

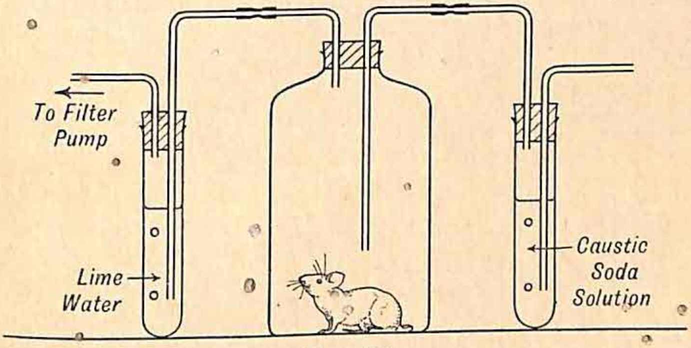

FIG. 121

*Expt. B.*—The apparatus shown in Fig. 121 is set up. A filter-pump draws a stream of air through caustic soda solution, which removes the small proportion of carbon dioxide that the air contains. The rest of the air passes into the bottle containing a living, white mouse, then through the lime-water in the boiling tube. After a minute or two the lime-water becomes milky showing that the mouse has produced carbon dioxide by its respiration.

## The respiration (breathing) of green plants

During the time a green plant is in the light, it is impossible to show the effects of its respiration, as other processes also take place at the same time, and their effects hide those due to respiration. For this reason, experiments on plant respiration have to be carried out in darkness.

Remembering the effects of animal respiration, we shall try to find out whether plants also produce carbon dioxide by their respiration. For this purpose we make use of a substance called brom-thymol-blue. In the presence of acids, such as carbon dioxide solution, this substance turns from a blue colour to a green one, and then to yellow.

EXPT. 1.—*To find out whether a plant produces carbon dioxide in the dark.*

Fill two test-tubes to within an inch of the top with distilled water, add about 10 drops of brom-thymol-blue solution,[1] and the minimum amount of lime-water needed to turn the solution blue. To one tube add a sprig of water weed, cork both tubes, and leave for 24 hours in a dark cupboard. At the end of that time, the liquid in the tube containing the weed has changed from blue to green, while that in the other tube is unchanged. Hence carbon dioxide has been formed.

If we use a land plant instead of a water plant we can show that carbon dioxide is formed by its action on lime-water.

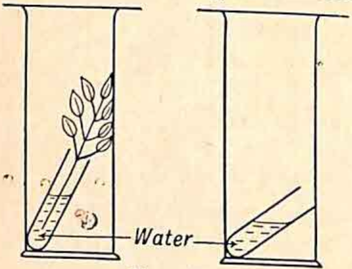

FIG. 122

EXPT. 2.—*To show the formation of carbon dioxide by a land plant.*

Fix up two gas jars as shown in Fig. 122, the only difference being the absence of the plant in one. Close them with well greased ground glass plates and leave for 2 days in a dark cupboard. At the end of that time test for carbon dioxide in both jars by adding a little lime-water and shaking. The lime-water turns milky in the jar which contained the plant, but not in the other. Evidently the plant has produced carbon dioxide.

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[1] The brom-thymol-blue solution is prepared as follows. Dissolve 0·1 gm. of the solid brom-thymol-blue in 100 c.c. of a mixture of 1 vol. alcohol to 4 vols. distilled water.

The respiration of ordinary twigs and leaves is not such an active process as in ourselves, but rapidly growing parts, such as germinating seeds, respire very vigorously. In their case we may hope to show that the changes they produce use up an appreciable proportion of the oxygen in the air.

EXPT. 3.—*To show the changes produced by the germination of seeds.*

Soak some seed peas in water for a day, and put layers of the soaked peas to a depth of 2 in. in two gas jars. Close the jars with well-greased plates and leave for a week in a warm place. At the end of the week remove the lid from one jar and immediately plunge in a lighted taper. It is put out, indicating lack of oxygen. The gas in the other jar will give a milkiness with lime-water, showing formation of carbon dioxide.

To make sure that the changes here are due to the respiration of the peas, and not to other actions, a third lot of the soaked peas should be boiled for 20 minutes to kill them, and make certain that no other living thing is present. The peas are then placed in a third jar and left with the others. The gas in this jar at the end of the week gives no milkiness with lime-water.

This experiment shows us that germinating seeds, such as peas, use up oxygen and give off carbon dioxide during their respiration. We have seen that the purpose of respiration in animals is to supply heat. Does it have the same purpose in plants? We do not usually think of heat in connection with plants, but we can attempt to find an answer to our question by experiment. For this purpose we shall again use germinating seeds, since in them the process of growth is occurring most vigorously.

EXPT. 4.—*To show that respiration is accompanied by heat production.*

Soak some fresh *seed* peas till signs of sprouting are just apparent. Kill half the peas by boiling them and cool them to room temperature again. Place the live peas in one vacuum flask to a sufficient depth to cover well a thermometer bulb, and place the killed peas in another to a similar depth. Choose two sensitive thermometers (reading to a fifth of a degree if possible) and check that they give the same readings when they are both immersed in the same beaker of water at room temperature. Place the thermometers in the flasks, and block the flask necks fairly tightly with cotton wool (Fig. 123). At the end of a day or two the temperature of the live peas has risen appreciably, 2°–4° C. or more, above that of the dead peas. Evidently even in plants, respiration is accompanied by the production of heat.

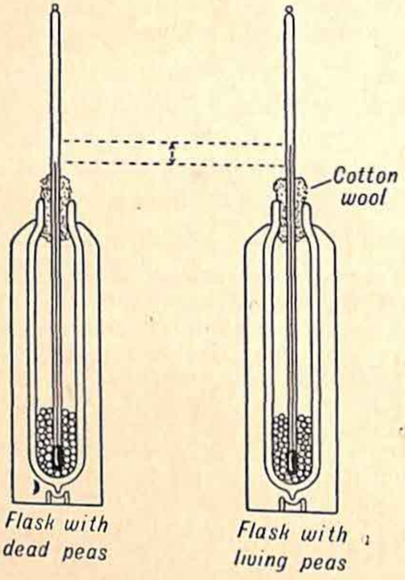

FIG. 123

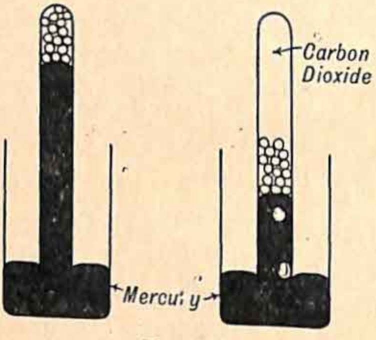

FIG. 124

Respiration in all the above cases has taken place in the air. Even in the first experiment small quantities of air are dissolved in the water. This kind of respiration is known as **aerobic** respiration. Sometimes, however, a plant is capable of producing carbon dioxide even when it is deprived of air.

EXPT. 5.—*To show respiration in the absence of air.*

Soak a few *seed* peas, remove the coats, and push the peas into an inverted test-tube of mercury (Fig. 124). After a day or two the level of the mercury has fallen. A little lime-water passed up into the space above the mercury turns milky. Evidently carbon dioxide has been formed. In a similar experiment, using peas killed by boiling, no changes occur in the tube.

Respiration of this type, in which air is not present, is known as **anaerobic** respiration (Gk. *an-*=not). It is not as efficient as ordinary respiration, and it cannot continue indefinitely, since another product, alcohol, is formed, and this acts as a poison to the plant if too much of it is present.

## CHAPTER 19

# SOME SIMPLE HEAT MEASUREMENTS. HOW WE REGULATE OUR TEMPERATURE

### How can we measure heat?

Heat is not a substance. It does not take up any space; it has no weight. Yet we often need to speak about a quantity of heat. Thus we may ask how much heat a ton of a certain kind of coal will give when it is burned. How can a quantity of heat be measured? Heat can be measured in terms of what it can do.

*Expt. A.—To examine the effects of supplying equal quantities of heat to different weights of water.*

The most convenient method of supplying a controlled quantity of heat to some water is by means of an electric immersion heater.[1] The heater, when operated off the same electric mains, will supply equal quantities of heat in equal times. The heater is mounted in a deep beaker which will hold about 2 pints of water. Dusters are wrapped round the beaker to reduce the loss of heat from the beaker to the surrounding air (p. 195).

The apparatus is assembled with 1200 gm. of water in the beaker. (The water can be measured out with a graduated cylinder.) The initial temperature of the water is taken and then the current switched on. *During the heating the water is constantly stirred.* After 5 minutes the current is switched off, the water stirred thoroughly, and the final temperature taken. The whole experiment is then repeated, with the same heater used for the same length of time, but with a smaller weight of water, e.g. 800 gm.[2]

In each case the result of supplying heat to the water is a rise in temperature. The rise for each heating is calculated. Now both quantities of water were supplied with equal quantities of heat, for the electrical conditions and the time were the same for each, but, it is found, the resulting rises in temperature are not equal. The rise in temperature is greater in the smaller weight of water. If, for example, the heat supply has raised the temperature of 1200 gm. of water by 8 degrees, then an equal supply will raise the temperature of 800 gm. of water by 12 degrees. If, therefore, we try to measure a quantity of heat by finding the rise in temperature which it produces in some water, we must agree upon the weight of water which is to be used.

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[1] See Appendix A. p. 210.

[2] The smaller quantity taken must be enough to cover the surface around the actual heating element.

## How we measure a quantity of heat

Physicists have agreed to measure a quantity of heat by reference to the rise in temperature produced in **1 gm.** of water. They give a special name to the quantity of heat which raises the temperature of 1 gm. of water by 1 degree Centigrade. It is called a calorie.

**A calorie is the quantity of heat which will raise the temperature of one gm. of water by one degree Centigrade.**

*Problem.—How many calories would be required to heat* 1000 *gm. of water from* 20° *C.* to 100° *C.?*

By the definition of the calorie,

1 gm. of water, in being heated through 1° C., requires 1 calorie. Now, in the problem, 1000 gm. of water are to be heated. This will require 1000 times as much heat, thus:

> 1000 gm. of water, in being heated through 1° C., require 1000 calories.

Next, the water is to be heated from 20° C. to 100° C., i.e. **the temperature is to be raised by 80° C.** This will require 80 times as much heat as for a rise of 1° C., thus:

> 1000 gm. of water, in being heated through 80° C., require $1000 \times 80$ calories.

The answer to the problem is $1000 \times 80 =$ **80,000 calories.**

You can probably see a short way of doing problems like this. Look at the last line. The result was obtained by multiplying together the **weight of the water** and **the rise in temperature.** This is a very convenient method, but you must take care to use the **rise** in temperature.

## How much heat does water give out when it cools?

Imagine that you have a can of cold water, and that you supply heat to it so that it gets hot. If now the hot water cools to its original temperature again, it will contain just as much heat as it had before it was heated. It must give out just as many calories in cooling as it took in during heating. During heating, the number of calories taken in is equal to the weight of the water multiplied by the temperature rise. Since in cooling to the original temperature, the temperature fall is the same as the temperature rise, **the number of calories given out is equal to the weight of water multiplied by the temperature fall.**

## British Thermal Units

In ordinary life you do not often weigh water in grams, nor measure temperatures in degrees Centigrade. You use pounds and degrees Fahrenheit. There is an alternative unit for measuring a quantity of heat; it is called a British Thermal Unit.

**A British Thermal Unit (B.Th.U.) is the quantity of heat which will raise one pound of water through one degree Fahrenheit.**

Gas-bills indicate the number of British Thermal Units which are produced when 1 cu.ft. of the gas is burned. Thus they may state that each cu.ft. of gas produces 450 B.Th.U.

Problems involving British Thermal Units can be solved just as easily as problems involving calories. If you multiply together the weight of water in pounds and the temperature rise in degrees Fahrenheit, you obtain the number of B.Th.U. supplied.

Coal-gas is sold by the therm and one **therm** is 100,000 B.Th.U.

## To investigate the heating of other substances

You have learned that 1 calorie will heat 1 gm. of water through 1° C. Will this heat supply raise the temperature of 1 gm. of any other substance by 1° C.? It is not convenient to experiment with the heating of a lump of solid substance by a Bunsen flame or an immersion heater. It is easier to use a can made of the substance and to heat it by putting hot water inside. A can specially made for experiments of this kind is called a **calorimeter.** You can see why it is given this name if you split the name into two parts—calori-meter; it means "heat-measurer".

EXPT. 1.—*Preliminary measurements to investigate the heating of a calorimeter.*

Apparatus: An extra thick calorimeter[1] made of a metal such as brass. It is fitted with a felt jacket. You will learn later (p. 195) that felt will not let heat pass through very easily, so the calorimeter (and the water inside it) will not lose much heat to the air.

Further apparatus: Measuring cylinder, beaker, thermometer, gauze, tripod and Bunsen burner.

Record the room temperature. Measure out about 100 gm. of water into the beaker (use the measuring cylinder) and heat it to about 50° C. Turn out the flame; stir the water, and then take its temperature. Quickly pour the warm water into the calorimeter (with its jacket on); stir continuously until the temperature is steady and then record the steady temperature.

What has happened to the temperature of the water? The water has lost some of its heat. What has happened to this heat? The felt jacket prevented much of the heat from going into the air. The heat must have gone into the calorimeter itself. What has happened to the calorimeter? It was at room temperature initially but at the end of the experiment it was at the same temperature as the water inside it. How can you calculate how much heat went into the calorimeter?

## How much heat is needed to warm 1 gm. of brass through 1° C.?

In an experiment like the above, the following readings were taken:

Weight of water used = 100 gm.
Temperature of water (before being poured into calorimeter) = 53° C.
Temperature of calorimeter originally (room temp.) = 15° C.
Steady temperature of water (after being poured into calorimeter) ≐ 35° C.

The weight of water was 100 gm. and the temperature fell by 18° C. So the water lost $100 \times 18 = 1800$ calories. But these calories went into the calorimeter. So the calorimeter received 1800 calories. What was the result? The temperature of the calorimeter rose from 15° C. to the final temperature of the water, 35° C., i.e. a rise of 20° C. Thus,

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[1] These can be obtained from Messrs Phillip Harris. A brass one weighs about 1000 gm.

1800 calories raised the temperature of the calorimeter by 20° C.

Now can you calculate how many calories would be needed to raise the temperature of the calorimeter by 1° C.? Clearly you must divide 1800 by 20. Thus,

90 calories will raise the temperature of the calorimeter by 1° C.

This, in itself, is not perhaps a very useful fact, because all calorimeters are not the same size. How many calories will be needed to raise **1 gm.** of brass through 1° C.? To answer this you must know the weight of the calorimeter. (It is rather heavy and should be weighed on a spring balance or lever balance capable of taking at least up to 1000 gm.) Suppose the calorimeter used in this experiment weighed 1000 gm. Thus,

90 calories will raise the temperature of 1000 gm. of brass by 1° C.

∴ 0·09 calorie will raise the temperature of 1 gm. of brass by 1° C.

You will note that less heat is needed to raise the temperature of 1 gm. of brass by 1° C. than is needed to raise the temperature of 1 gm. of water by 1° C. This is an important piece of information. You should now repeat the whole of the above experiment as below, using, if available, a calorimeter made of a different metal.

EXPT. 2.—*To find how much heat is needed to raise the temperature of 1 gm. of iron (or brass, etc.) by 1° C.*

Apparatus: Thick iron (brass, etc.) calorimeter provided with a felt jacket, spring (or lever) balance maximum 2000 gm.), beaker, thermometer, measuring cylinder, gauze, tripod, Bunsen burner.

Remove the felt jacket, weigh the calorimeter on the spring balance and replace the jacket. As it is rather rough to assume that the initial temperature of the calorimeter will be room temperature, it is filled with cold water and allowed to stand. Meanwhile, measure 100 gm. of water (how?) into the beaker, warm this to about 50° C. and turn out the flame. Read the temperature of the cold water in the calorimeter, pour away this water and drain the calorimeter. Read the temperature of the warmed water and quickly pour it into the calorimeter. Stir well and read its temperature when steady. Calculate the rise in temperature of the calorimeter and the fall in temperature of the warmed water and work out the result in the manner shown on p. 174.

Can you understand why a *thick* calorimeter is used? If you are in any doubt, try the experiment with a thin can (e.g. a cocoa tin).

## Some interesting facts about the heating of various substances

Here are some of the values of the quantity of heat needed to raise the temperature of 1 gm. of various substances by 1° C. Some can be obtained by the method of Expt. 2, others by different methods.

| Substance | No. of calories to raise 1 gm. of substance by 1° C. |
|---|---|
| Water | 1 |
| Aluminium | 0·219 |
| Brass | 0·088–0·093 |
| Copper | 0·093 |
| Iron | 0·119 |
| Mercury | 0·033 |
| Marble | 0·21 |
| Methylated spirits | 0·6 |
| Earth's crust | 0·2 (average) |

What do you notice about these values? All of them are less than that for water, and metals have very low values. So whereas water requires a large number of calories to heat a given weight of it through a certain range of temperature, the same weight of a metal requires considerably fewer calories to produce the same rise in temperature. This is one reason why metals are used for making boilers and kettles; they do not need so much heat to make them hot and more heat is available for heating the water. Similarly, the mercury in a thermometer bulb takes very little heat from its surroundings in reaching the required temperature. Have you noticed that a piece of metal (such as an iron seat) feels quite hot after the sun has been shining on it and yet the water in a nearby swimming pool remains fairly cool? You should now be able to explain this.

When a hot body cools, it gives out the heat which was used in making it hot. Hot water therefore gives out more calories in cooling through a certain range of temperature than would a piece of metal of the same weight in cooling through the same range. The water cools more slowly; people sometimes say it "holds its heat". This is one reason why a hot-water bottle is more effective than a hot lump of metal (of the same weight) for warming a bed.

## How the sea affects climate

Water heats up more slowly than other substances, but, when warm, gives up its heat more slowly. From the table on p. 175 you can see that whereas 1 calorie will heat 1 gm. of water through 1 degree, 1 calorie will heat 1 gm. of rock through 5 degrees (for only 0·2 calories are needed to produce a rise of 1 degree). Thus, if the land and the sea each receive the same amount of heat from the sun, the land will get hotter than the sea; but when the sun is hidden (as at night, or during winter time) the sea will "hold its heat" much better than the land.

Great Britain is entirely surrounded by sea. In summer, the air does not often get excessively hot, because the sea remains fairly cool. In the winter time the sea, which cools slowly, keeps the air from becoming excessively cold. The result is that our climate is never extreme. Usually, our winters are only moderately cold and our summers seldom very hot.

Moscow is in the same latitude as Edinburgh, but the climate in the Russian city is much more extreme. With very little sea near, the summers are hot, because the land heats up quickly, and the winters are very cold, because the land soon loses its heat.

The Sandwich Islands, although in the same latitude as the West Indies, are noted for their even climate. The temperature, winter and summer, ranges from about 75° F. to 90° F.

## Seaside breezes

Wind and breezes consist of currents of moving air. When the air in a certain district becomes warm, it rises (p. 187), and cooler air from an adjacent district flows in, near the ground, to take its place. This flow of cooler air constitutes a breeze.

At the seaside, on a sunny day, the land becomes warm more quickly than the sea and the air over the land rises. Cool air blows in from the sea; there is a sea breeze (Fig. 125). After the sun has set from a clear sky, the land cools more quickly than the sea; soon the sea is warmer than the land. A breeze blows seawards from the land (Fig. 126).

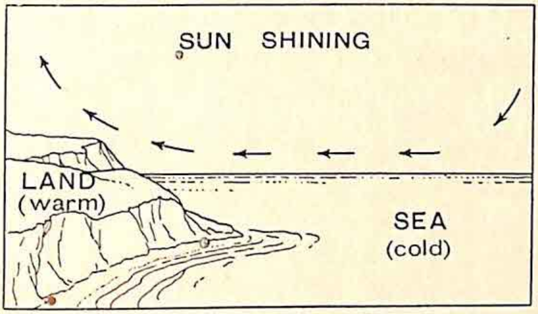

FIG. 125.—Sea breeze

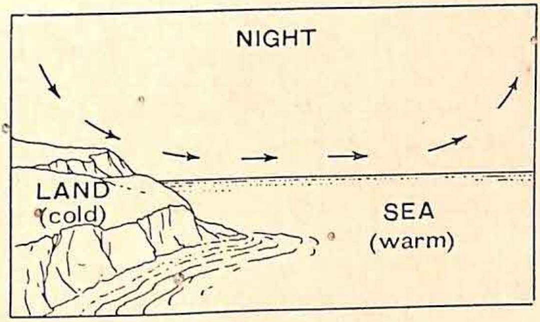

FIG. 126.—Land breeze

## A popular mistake

You should have no difficulty now in understanding that the **temperature** of an object is not the same as the **heat** the object contains. People who have not studied science often use the word "heat" when they mean "temperature". To make the difference clear, let us imagine that a bath is half full of cold water. Which would be the better way of warming it:

(*a*) by adding a cupful of boiling water; or
(*b*) by adding a bucketful of boiling water?

Of course, you would choose the bucketful. It has more heat to give to the cold water, but it is at the same temperature as the cupful.

Again, which would you choose of these two:

(*a*) a red-hot cinder; or
(*b*) a bucketful of boiling water?

You would choose the water because it could give more heat to the cold water, in spite of the fact that the cinder has a higher temperature.

You must be very careful to distinguish between heat and temperature. The temperature of an object tells you how hot it is, but **the heat which an object can give out depends upon the weight of the object, the substance of which it is made and the temperature fall.**

## Does supplying heat always raise the temperature?

When heat is supplied to a substance you expect it to get hotter, i.e. its temperature is raised, and you have just learned how you can use this fact to measure heat. But we must now enquire whether a supply of heat always raises the temperature. You can find the answer to this problem practically, thus.

EXPT. 3.—*To examine the temperature of boiling water.*

Apparatus: Tin can, thermometer, tripod, gauze and Bunsen burner.

Half-fill the can with water and heat it over a moderate Bunsen flame. Find out how hot the water is (*a*) when it begins to boil, (*b*) after it has been boiling for 5 minutes, (*c*) when the gas has been turned on full and the water is boiling furiously.

Then remove the flame and observe what happens to the temperature of the water.

## Supplying heat does not always produce a rise in temperature

In the above experiment you found that the water boils at about 100° C. (cf. p. 31), and that once the water is boiling it does not become any hotter. Even after 5 minutes the temperature is the same, and it is not altered by turning the gas on full. Further, as you learned from the experiment on the fixed points of a thermometer (p. 32), the temperature of steam, too, is approximately 100° C. There is no doubt that in Expt. 3 heat is being supplied to the water but this heat does not raise the temperature. Is such heat just being wasted or is it used in doing something else? When the flame was removed, the boiling stopped and the temperature began to fall. So the supply of heat was necessary to maintain the boiling, i.e. the change of water into steam. It seems that the heat is used in causing the change of state from water into steam and this heat does not cause a change in temperature.

Changing water into steam is an example of a **change of state;** a liquid is changed into a vapour. Let us now examine another change of state.

### Another case in which addition of heat causes no temperature change

When ice melts to form water we have a change of state; a solid changes into a liquid.

Expt. 4.—*To find how the temperature of ice is affected by adding heat to it.*

Apparatus: Pyrex beaker, thermometer, gauze, tripod and Bunsen burner, clock.

Half-fill the beaker with chips of ice and place a thermometer well into it. When the thermometer reading is steady, gently heat the beaker and ice over the Bunsen flame, stirring continuously. Read the thermometer every ½ minute for about 5 minutes. It is important to keep the contents of the beaker well stirred.

In this experiment heat is supplied to the ice, but while the ice is melting, the temperature remains unchanged, providing that the ice and water are kept thoroughly mixed. Again, heat is used in causing a change of state.

### Latent heat

As the heat used in causing a change of state does not affect temperature, we call it **latent heat.** "Latent" means hidden, and in these cases the heat is hidden because a thermometer does not show that the substances have received it.

## Can latent heat be recovered again? Scalds

When any solid changes into a liquid, or any liquid changes into a gas, heat is absorbed during the process. You would expect that when the liquid changes back into a solid, or the gas into a liquid, this heat will be released again. This is just what does happen. When steam condenses to water, it gives up its latent heat. For this reason, a scald caused by steam is more severe than one caused by boiling water. The steam not only gives the heat to your flesh that boiling water would, but also its latent heat, which is considerably more.

EXPT. 5.—*To obtain a rough value for the number of calories required to change* 1 *gm. of boiling water into steam.*

Apparatus: Small can (about 200 c.c.), graduated cylinder, tripod, gauze, Bunsen burner and clock.

Put 100 gm. of cold water into the can and take its temperature. Heat it over a steady Bunsen flame which, as far as possible, is shielded from draughts. Find the time taken for the water to reach the boiling point. Then, *maintaining the same sized flame*, find the additional time which is taken for all the water to boil away.

How many calories are supplied to the water to raise its temperature from that of the room to boiling point?

How many calories does the flame supply per minute?

Assuming that the rate of supply of heat is unchanged, how many calories are supplied to the boiling water to change it all into steam?

How many calories are needed to change 1 gm. of water at the boiling point into steam?

## The latent heat of steam

In referring to latent heat it is usual to state the number of calories required to change the state of 1 gm. of the substance without raising its temperature. Thus, the term "the latent heat of steam" means the number of calories which will convert 1 gm. of water at 100° C. to steam at the same temperature. Now compose a corresponding statement to explain the meaning of "the latent heat of fusion (melting) of ice".

The latent heat of steam is large; the quantity of heat required to convert 1 gm. (or any other weight) of boiling water into steam is several times (five or six) the quantity needed to bring the same weight of cold water to the boil. In a steam engine, for every ton of coal used in bringing the water to the boil, several tons are used in changing it into steam.

### Why do icebergs melt very slowly?

The heat required to change 1 gm. of ice into water is not so much as that required to change the same weight of boiling water into steam, but still it is considerable. Roughly, it takes about as much heat to melt a piece of ice as it takes to raise the temperature of the resulting water up to the boiling-point. Before ice can melt, it has to be supplied with the necessary quantity of heat, and this is one of the reasons why melting is a slow process. You may have noticed that, after a heavy fall of snow, thawing takes place quite slowly, even in sunshine. For this reason, too, icebergs may drift thousands of miles southwards from the Arctic Ocean before they melt completely.

### Evaporation

Pools of water in the road dry up if the weather is fine. What happens to the water? The pool dries up because the water changes into vapour. Yet at no time would you say that the water of the pool boils. This drying up process is different from boiling in the following ways:

(1) It takes place at an ordinary temperature, and not at 100° C.
(2) It takes place calmly; bubbles of steam do not jump up from inside the water.

This process is called **evaporation.**

Some liquids evaporate more quickly than others at ordinary temperatures. Water evaporates rather slowly: petrol and ether evaporate quickly.

Expt. 6.—*To find the effect of evaporating different liquids.*

*Note.*—Petrol and ether are **dangerous** liquids. Take care not to have a flame near them because they catch alight very easily.

Put two or three drops of (*a*) water, (*b*) petrol and (*c*) ether, in turn, on the palm of your hand. Write down all that you see and feel.

### Evaporation has a cooling effect

In the above experiment, you find that the water does not evaporate very quickly; you cannot see that any evaporation is taking place, but the petrol and ether soon disappear. (Your sense of smell tells you that the petrol and ether are changing into vapours.) At the same time the part of your hand from which the liquid evaporates feels cold. This cooling effect of evaporation can be shown in another way.

*Expt. B.—To show the cooling effect due to evaporation.*

A small pool of water is made on a block of wood and a small metal can, containing some ether, is stood in the water (Fig. 127). The ether is made to evaporate quickly by blowing a current of air through it from bellows. (The blowing must not be so vigorous that ether is splashed out of the can.) Soon drops of moisture appear on the outside of the can and, after a short time, the water underneath freezes, so that the can is fastened to the block of wood.

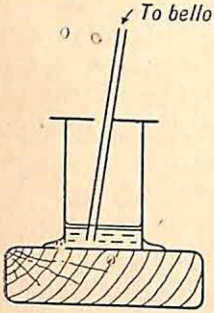

FIG. 127

## Why does evaporation cause cooling?

The experiments show that rapid evaporation has a cooling effect. What is the explanation? In neither of the experiments was there a visible source of heat, e.g. a flame, and yet, as you have learned, heat is needed to change a liquid into a vapour. In Expt. 6 the heat required for evaporation was taken from your hand; in Expt. B it was supplied by the metal can, by the water underneath it, and by the ether itself. The cooling effect of evaporation is thus another example of the need of latent heat in a change of state.

## Some uses of the cooling effect of evaporation

By spraying a liquid which will evaporate easily on to a small area of the body, the nerves can be numbed with the cold, so that a doctor can perform a small operation without causing much pain. Children's teeth are removed painlessly by "freezing" the gums by a similar method. Dentists use a liquid called ethyl chloride for this purpose.

A spray of scent on the body in summer time helps to keep one cool by its slow evaporation.

In hot countries water is kept cool by storing it in large jars made of a porous substance (something like flower-pots). The water very slowly trickles through the little pores and then evaporates into the air. This keeps the jar and the water cool.

The same idea is applied in this country to keep butter cool in the summer. The dish of butter is placed in a porous vessel (with a lid) which has been soaked in water. As the water evaporates, it cools the vessel and the butter inside.

You will learn later (Book II) how a refrigerator works; you will find that it depends essentially upon the latent heat which is taken in when a liquid evaporates.

**Our own temperature**

You may have noticed that certain thermometers have the words "**Blood Heat**" marked on them at a temperature of about 37° C. or 98° F. The term "Heat" in this connection is of course not correct, and the word "Temperature" ought to be used instead (see p. 177). The actual figures apply only to human beings, but they mean that the temperature of our blood is normally fairly steady when we are in good health. It is perhaps a little surprising at first, if you consider two extreme cases. There is little difference between a man's temperature while he is crossing the tropical regions in the hottest season, and while he is on a sledge near the South Pole. How does the body manage to keep such a marvellously steady temperature? Clothes help (p. 195), but even if wrapped up, a stone would soon become hot in the tropics and cold at the Poles. The differences between the two cases must have something to do with our bodies.

You have learned that oxygen is needed to oxidize substances in our bodies, and so produce heat. If we move about or take any form of exercise, more heat is produced, and we feel warm. If we continue our exercise two other things are noticeable. First of all, someone else touching us will notice the increased warmth of our skin. This means that more of our blood has come near the surface of the body, where it can be cooled by contact with the air. A little later visible drops of moisture are noticeable on certain parts, particularly on the face. These are beads of perspiration. Our skin is always giving off small quantities of moisture. To turn this from liquid to vapour requires heat, and since this heat is largely supplied by the body, perspiration helps to cool us. During exercise we perspire more freely, and so get extra cooling to compensate for the extra heating due to the exercise. On a hot day we also perspire more, since the body cannot lose heat so readily in other ways. Perhaps you can now understand why hot, dry weather is more comfortable than hot, wet weather. When it is wet or "muggy" the perspiration cannot evaporate so freely, and so our cooling-methods are much less efficient. In really dry conditions this cooling by evaporation of perspiration is very efficient indeed, and men have been able to remain for a considerable time in a room hot enough to cook meat. Men who have to work in very hot conditions drink considerable quantities of liquids in order to be able to perspire freely. Similarly, in very hot weather we all feel so much more thirsty. The extra liquid is needed to make up for the loss by perspiration.

In special circumstances our temperature does rise. If the rise is small we are said to be "feverish". This often happens when disease germs have managed to invade our blood. If the rise is more than a degree or two we are very ill, while a rise of 10° F. or more is usually fatal.

## Warm-blooded and cold-blooded animals

We are used to thinking of certain kinds of animals, such as ourselves, as **warm-blooded.** The kinds of animals to which this term can be applied are the mammals and the birds. All the rest are **cold-blooded.** These descriptions are not always correct. On a hot day in the tropics the temperature of a "cold-blooded" lizard would be higher than that of a man. "Cold-blooded" animals are those which cannot regulate their temperature, which is always, within a degree or two, that of their surroundings. This is a big disadvantage in many ways. The chemical reactions which govern animal life within the body take place best at about 40° C. At lower temperatures these take place more slowly. Consequently, on a cold day a cold-blooded animal is necessarily very sluggish, while a warm-blooded animal can be as active as on a warm day.

## CHAPTER 20

# THE TRANSMISSION OF HEAT

### How does heat travel?

Although you are not yet able to say what heat is, it is time for you to decide whether heat does travel from one place to another, or even from one part to another of a single substance; and, if so, to try to obtain some picture of the process. First, in answer to the question, "Does heat travel?" you will no doubt answer, "Yes, because the heat from the white-hot sun reaches the earth", or "Yes, because, although the fire causes a draught up the chimney, we can warm ourselves by standing in front of it". Each answer is correct; but what are you going to reply to the next question; "Is this the only way by which heat can travel from one place to another?" The following experiments will help you to provide the answer.

*Expt. A.—Can heat travel from one part to another of a solid substance?*

A small can of water placed alongside a Bunsen flame (say 3 or 4 in. away) would be warmed, slightly, just as you warm yourself in front of the fire. This is prevented by placing a sheet of asbestos between the flame and the can. Can heat pass from the flame into the water by any other process?

A copper or brass rod, about $\frac{1}{4}$ in. diameter, is bent and pushed through the asbestos sheet so that one end is well in the water in the can and the other in the Bunsen flame (Fig. 128). The water is kept well stirred and temperatures recorded on the thermometer every 2 minutes for about 10 minutes. The temperature rises gradually; therefore heat must have travelled from the flame into the water, and there is only one possible way—along the rod.

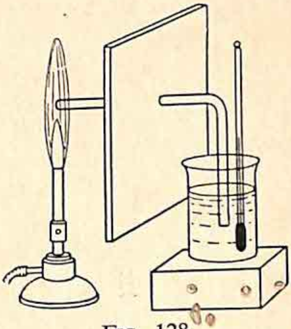

FIG. 128

*Expt. B.—How is the whole of a liquid raised in temperature by supplying heat to one part of it?*

A flask containing water is warmed by a Bunsen and a thermometer inserted so that the bulb is just below the surface of the water (Fig. 129). This time, the water is not disturbed by stirring, but the thermometer also shows a rise in temperature, so that heat has once more passed from the flame to the top of the water.

But, has the heat passed up through the water to the thermometer in the same way as it passed along the metal rod in Expt. A?

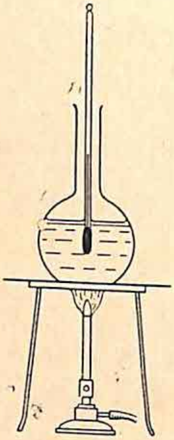

FIG. 129

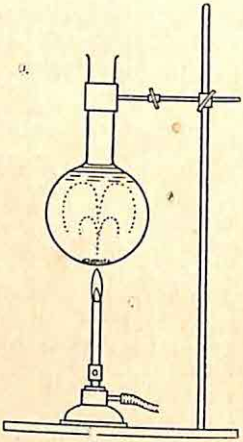

FIG. 130

To answer this, the experiment is repeated with slight changes. Water is poured into the flask and left until it is quite steady. A small quantity of fine, wet sawdust is then dropped to the bottom of the water (the thermometer is not needed), and a **small flame** is used to heat the flask. Observation shows the sawdust, originally at the bottom, following a track similar to that shown by the dotted lines (Fig. 130).

As soon as the water is heated, it begins to move appreciably and to flow upwards, i.e. after **heating** one portion of the water, this is set in motion upwards, and carries its heat along with it.

*Expt. C.—To observe the flow of air set in motion by a small source of heat.*

A strong beam of light is sent from a lantern across the darkened room on to a screen, showing there a bright, circular patch of even illumination (Fig. 131). A small Bunsen flame—even a candle flame will do—is then placed about 6 in. below the beam of light, and the movement of the air above the flame and through the beam is clearly interpreted on the screen. The heated air flows upwards in just the same way as the heated water did.

Now this movement of matter could not have happened in the copper rod, because copper is a solid and solids do not flow. Further, most of the space between the sun and the earth contains neither solid, liquid nor gas; thus the process by which the sun's heat reaches the earth cannot be either of those illustrated by the foregoing experiments.

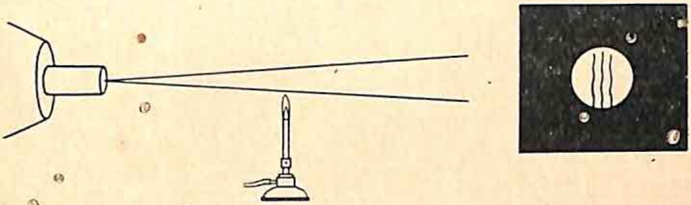

FIG. 131

It appears therefore that there are three ways in which heat may travel; these are;

(1) By **the process of Conduction** (as in Expt. A) in which the heat is "handed on" from particle to particle of the substance, without any apparent movement within the substance.

(2) By **the process of Convection** (as in Expts. B and C) in which the heat is conveyed or carried by the particles of the substance which received it.

(3) By **the process of Radiation,** in which the transference takes place without the assistance of solid, liquid or gas.

In the first two processes, the substance in which conduction or convection takes place is warmed. You would expect this, but what you would not expect is that the transference by radiation takes place through a space without any effect upon the temperature of the space itself. What passes from the sun to the earth, or from the fire across the room, is evidently not heat according to the everyday use of the term. If it were, it would warm the space through which it travels just as the solids, liquids and gases in experiments recently performed were warmed by the passage of heat through them. To distinguish it, it is described, and always referred to, as the radiation from the sun (or the fire). A rise in temperature is only produced when this radiation is absorbed by some substance in its path.

You should note, moreover, that the space through which the radiation travels need not be absolutely empty. The sun's radiation penetrates the atmospheric belt around the earth; it even passes through the glass panes of our greenhouses, and the radiation from our homely fires traverses the room "filled" with air. How then, you will ask, is the air of the atmosphere or of a living-room warmed?

### On warming the atmosphere

The sun's radiation penetrates the atmosphere, and is absorbed by the surface layers of the earth. In consequence, there is a rise in temperature, and the warmed layer transfers, by the process of conduction, some of its newly acquired heat to the layer of air particles in contact with its surface. These warmed air particles rise as a convection current from the earth; they are replaced by cooler ones which in turn are warmed by conduction from the earth, and so the process continues. Experience shows that the result is not equally effective in different latitudes. Further, the ultimate rise in temperature of the air is greater over land than over water. You should now be able to apply this explanation to the similar process of warming the air in a room by means of a coal fire. Again, if the atmosphere directly absorbed the sun's radiation you would expect the upper layers to be warmer than the lower ones: the evidence of snow-capped mountains clearly proves that this cannot be true.

### Conductors of heat compared

Having accepted the process of conduction of heat in solids (Expt. A) two questions arise:

(1) Do all solids conduct heat equally well?

(2) Can heat be transferred by conduction through either a liquid or a gas?

To answer the first question, three experiments are performed.

*Expt. D.—Do metals conduct heat equally well?*

The apparatus consists of a brass cylindrical can, closed at the top by a cork carrying inlet and outlet tubes. Into the base, long cylindrical rods of the metals, e.g. copper, brass, aluminium, iron, zinc, to be tested are brazed (Fig. 132 (*a*)). These rods must have the same diameter and the same length of each above the base inside the can. They are thinly coated with candle wax, which holds a small wire indicator (Fig. 132 (*b*)) in place at the top of each rod. If the wax melts, the indicator will slide down the rod until it comes in contact with solid wax.

Steam is blown through the can (what will be the final temperature inside the can?), some wax on each rod melts, and the indicators slide down their respective rods. *No observation* should be taken until the movements of the indicators have ceased. **The best conductor is that metal along which the wax melts farthest.** Write down the order of conducting power (or conductivity) of the metals by noting the positions of the respective indicators. Is any of these metals outstandingly superior to the rest?

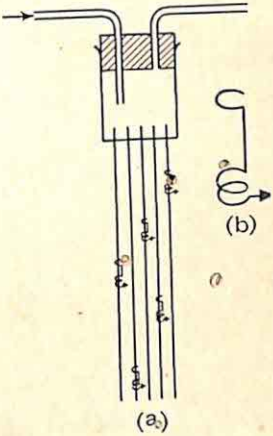

FIG. 132

Clearly, all metals do not conduct heat equally well. Can we say the same for other solid substances many of which are in common use? The method of the experiment just performed is not suitable for such materials as wood, glass, ebonite, cardboard and asbestos; the idea of it is still used, but the details, especially the shape of the substance, must be modified.

*Expt. E.—Do common substances such as wood, cardboard, glass, etc. conduct heat equally well?*

The apparatus for making this comparison consists of a brass cylindrical steam chest with inlet and outlet tubes soldered into its sides. This is sunk in a block of wood so that the top of the steam chest is level with the top of the wood. A solid disc of brass, having the same diameter as the steam chest, has a hole, into which a thermometer can be inserted, bored into it through the side and reaching just beyond the axis.

The specimens to be tested must be in the form of thin discs, all of the same diameter, just slightly larger than the steam chest, and having exactly the same thickness, about 2 mm. Each in turn is placed between the steam chest and the brass disc (Fig. 133), and a thermometer is inserted in the disc. Steam is blown through the chest, and the thermometer observed until it indicates a steady temperature which is then recorded.

Heat from the steam chest is conducted through the disc of material into the brass disc and warms it. The best conductor warms it to the greatest extent; hence the higher the temperature recorded by the thermometer, the better the conductivity of the material under test.[1] Now you can write down the order of conductivity from the records of temperatures taken.

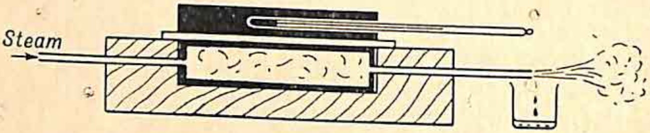

FIG. 133

You have now two orders, one for metals and one for other common substances, but you do not yet know anything about the conductivity of a metal, e.g. iron, compared with that of a common substance such as wood.

*Expt. F.—To compare the conducting powers of a metal (iron) and wood.*

The top of a block of wood is planed to a smooth, flat surface and a number of broad-headed iron nails are driven, in some form of design, through this surface into the block, so that their heads are level with the wood. A thin sheet of paper is then pasted over wood and nail-heads, and, when this is dry, a Bunsen flame is gently played over the whole surface of the paper. Most of this is quickly charred, but the design is clearly marked by spots of unchanged paper. The charred paper covers the wood (scrape it to make sure), the uncharred, the nails. Which substance conducts heat more readily from the paper?

---

[1] Although, when the brass disc is hotter, it transfers heat to its surroundings more readily than at a lower temperature, the qualitative character of the result is not falsified.

Note that from the order compiled in Expt. D, iron is by no means the best conductor amongst the metals.

## Another method of indicating temperature

Sometimes thermometers or wax coatings are inconvenient for use as temperature indicators; then, it is necessary to devise another method of showing whether a rise in temperature has taken place and if so, how much of a substance has reached or exceeded a certain temperature. The new indicator is a piece of paper, usually filter paper, which has been chemically treated to make it sensitive to heat.[1] This heat-sensitive paper when cold has a slightly damp feeling and is pink in colour; when it is warmed it dries completely, at a certain temperature becoming greenish blue in tint. On cooling, the sensitive substance takes up moisture from the atmosphere and so regains its pink colour.

## Do liquids conduct heat?

You have already learned (Expt. B) how convection currents are caused by heating a liquid. If this liquid is to be tested as a conductor of heat, you must be sure that any rise in temperature which may be observed is in no way due to the process of convection within the liquid. As warm convection currents are produced by heating a liquid at the bottom, the best way to avoid them is to heat the liquid at the top.

*Expt. G.—Do liquids conduct heat?*

About three-quarters of the length of a test-tube is wrapped round with dry sensitized paper, and water poured in the tube until about $\frac{1}{2}$ in. above the top of the paper. To heat the water at the top, we use the method of Expt. A, but do not push the brass rod more than $\frac{1}{4}$ in. below the surface of the water (Fig. 134). The rod is heated as before, and heat is conducted by it to the top of the water. Is the water heated any further? Watch the paper; then answer the question.

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[1] The paper is prepared by dipping sheets of filter paper in a solution containing 5 per cent of cobalt chloride, and 1 per cent of calcium chloride, then drying them as far as possible by evaporation.

*Expt. H.—Do liquids conduct heat equally well?*

This is a variation of the previous experiment, the only difference being that two liquids, e.g., water and mercury, are heated from the same source in such a way that all the conditions are the same for both liquids. Compile a list of these conditions.

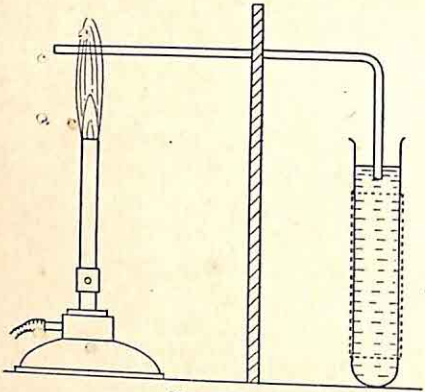

FIG. 134

The arrangement is shown in Fig. 135. As before, observations are not taken until temperature changes are finished. (How will you tell this by observation of the sensitized paper?) The length of paper turned blue corresponds to the length of melted wax in Expt. D. Which liquid is the better conductor?

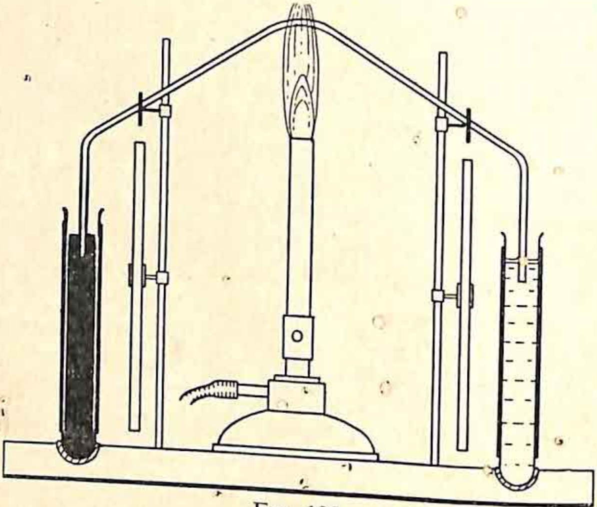

FIG. 135

By substituting other liquids for water and comparing the conducting power of each in turn with that of mercury, it is observed that mercury alone among liquids is a good conductor of heat: all the rest are bad conductors. Mercury is the only metal which is liquid at ordinary temperatures, but compared with other metals, e.g. copper or iron, it is much inferior as a conductor of heat.

## Is heat conducted through a gas, e.g. air?

There is no simple experiment which will answer this question. The particles of a gas move so freely that convection currents are easily set up in it, so easily in fact that the method adopted for testing the conductivity of a liquid would not be good enough to avoid these currents in a gas. All gases will conduct heat, but always extremely badly; they are much poorer conductors even than liquids. (This extremely low conducting power adds to the difficulty, mentioned above, of devising a successful, simple experiment to establish the information.) In the daily applications of conductivity which will be considered, the bad conductivity of air is of great importance; you must accept this scientific fact without experimental proof.

## Summary of information respecting conductivity of various substances

(1) Metals are good conductors, copper and silver being easily the best.

(2) Common substances such as wood, cardboard, rocks, asbestos and rubber are poor conductors.

(3) Excepting mercury, liquids are bad conductors.

(4) Gases are very bad conductors.

## Good and bad conductors of heat in daily life

A good conductor not only conducts heat readily through itself; it conducts heat into itself quickly from a warmer substance with which it happens to be in contact. If the temperature conditions are reversed, the good conductor transfers heat readily to a cooler substance in contact with it. On the contrary, a bad conductor transfers its heat less readily to a colder substance, and accepts heat less readily from a warm substance. This is easily appreciated if you feel, with your warm hand, the metal gas-tap on the bench and the wood in which the tap is mounted. Both are at the same temperature, yet the tap feels colder than the bench, because, being a good conductor of heat, it takes heat from your hand more rapidly than the wood of the bench, which is a poor conductor.

**When a good conductor is used** in some daily operation, it is because it will readily conduct heat into itself and, if required, liberate it to some other substance.

Kettles and saucepans are made of iron or aluminium because these metals conduct the heat efficiently from the fire, gas flame or hot-plate to the water and other contents in them.

For a similar reason, boilers for locomotives and steam generators in factories are made of steel (see also p. 175). In some instances copper is used because it is a much better conductor of heat, but in all cases where high-pressure steam is required, steel is preferred because it is harder metal and better able to stand the strain imposed by the pressure. The tip of a soldering iron is made of copper (notice the green colour when it is heated in the Bunsen flame). In use it readily conducts its heat into the solder to melt it, and also into the two pieces of metal which are to be united. Mercury being the only good liquid conductor, you will now appreciate the choice of it for the construction of a thermometer.

**Instances of bad conductors** are much more numerous and are frequently applied for personal convenience or comfort. Wooden cooking spoons are preferred to metal ones, soldering irons have wooden handles, so too have many metal tea-pots, and some silver teaspoons have a small wooden holder fitted round the end of the shank. The poor conductivity of rocks and soil plays its part in the process of warming the atmosphere (pp. 177, 188). Radiation from the sun on being absorbed by the rocks of the earth's surface is not easily conducted into the earth; hence the surface is appreciably warmed. Maximum and minimum thermometers buried at a depth of only 3 ft. show that there is practically no variation of temperature throughout any particular day, although there will be some slight difference in actual records taken on, say, June 21st and December 21st.

**The bad conductivity of air** plays an important part not only in our lives, but also in those of birds and animals. Have you not noticed the common sparrow with ruffled feathers on a cold wintry day? The ruffled feathers enable the bird to keep round its body a thicker coat of air, through which heat from the body is conducted very badly. This helps to keep the bird warmer in wintry weather. Cats obtain the same advantage by making their fur "stand on end". Turning your attention to the scientific aspect of clothing, you should realize that its efficiency in promoting bodily warmth, without uncomfortable excess, depends very largely upon the bad conductivity of air. Loosely woven materials, such as wool and flannel, have more air intermingled with the fabric than materials made of cotton and linen. They are correspondingly more serviceable in hindering loss of heat from the body in cold weather, or gain of heat by it in very hot weather. The felt jacket used in Expt. 1, p. 173, reduces the passage of heat from the good conducting walls of the calorimeter to the surrounding air. Its texture is woolly, and there is usually a layer of air between the felt and the metal.

Other interesting examples of the service rendered by bad conductors are the double-walled tents and huts used by explorers in the Arctic to protect them from cold, or in Equatorial regions to protect them from heat. The walls of buildings (e.g., garages) which are made of wood instead of brick or stone usually incorporate three different bad conductors. The outside layer is made of wood, the inside layer of asbestos boarding, and there is an air space between the two. In countries which experience severe winters, the windows of dwelling houses, factories and offices consist of doubled panes of glass separated by a narrow air space. Finally, a block of ice may be kept without much loss by melting, if placed in the middle of a large box, e.g. a tea chest, filled with sawdust, packed loosely. Wood is a poor conductor and the many fragments of sawdust do not make good contact with each other, yet the preservation of the ice is due more to the bad conductivity of the countless air pockets between the fragments of the sawdust, than to the poor conductivity of the sawdust itself.

## More about convection

Expt. B showed that a hot convection current rose in a liquid. You will remember from earlier work that, on being heated, a liquid expands and consequently becomes less dense. Since the various parts of any liquid are free to move, you cannot keep a warm portion of it underneath a cooler portion, which is denser; as the warmer liquid rises, cooler liquid flows in to take its place. The sawdust tracks, which you watched in the early experiment, do not show you all that was happening. Now if this argument is correct, it ought to be possible to produce convection currents in a liquid (or a gas) not only by heating it at the bottom but also by cooling it at the top so as to increase the density there.

*Expt. J.—To show the production of a cold convection current in a fluid.*

A large beaker is nearly filled with luke-warm water and a small piece of ice is carefully floated at the side of the surface (Fig. 136).

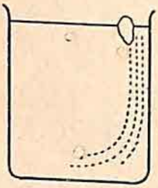

FIG. 136

A drop of dye[1] is laid beside the ice and the downward track of a cold convection current is observed in a few seconds.

The corresponding result for gases is just as easily proved by holding a beaker, containing a mixture of ice and salt (or calcium chloride), a few inches above the beam of light used in Expt. C.

## Convection currents in daily use

The applications of convection currents are almost as numerous as those of conduction. Moreover, it is interesting to note that some of the benefits derived from convection currents result from natural processes, and are not due to the intelligent application, by man, of the scientific knowledge he has acquired.

The trade winds and the monsoons, about which you learn in geography lessons, are just air convection currents on a very large scale. Land and sea breezes (p. 177), which occur only on fine days, when there is very little or no general disturbance of the air, are small-scale currents. Whereas the monsoon affects the whole of India, land and sea breezes are effective over a range of only a few miles on either side of the shore.

Man's ingenuity in using the principles of convection is chiefly applied to the problem of heating large buildings, of supplying hot water in large quantities for general use in houses and hotels, and of ventilating large buildings and the underground passages of tube railways.

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[1] A solution of methylene blue in alcohol is used in this demonstration.

## Ventilation at home

Many living-rooms are heated by coal or gas fires which cause a hot convection current to rise up the chimney. Coal or coal-gas will not burn without a supply of fresh air, and therefore the removal of the hot gases up the chimney must be compensated by an inflow of fresh air, even when the doors and windows are "shut". This ventilation is sometimes not enough and a window must be opened.

## A little history

You are familiar with the pipe method of heating the various rooms of the school. Long before this method was adopted, the Romans warmed their rooms, even the rooms of barracks, by means of hot air currents. They built one large brick furnace (called a hypocaust), placing it just outside, and below the level, of the building to be heated. Wood was burned in the furnace; the smoke and hot gases, instead of passing up a chimney, flowed along a connecting channel to the spaces under the stone floors, and between the stone or brick walls of adjacent rooms. They then passed out into the air at the top of the building. This method was not a good one; it was difficult to control the heating; it could have rather disagreeable results, and was useless in assisting ventilation of the rooms occupied. Nevertheless, it was the best available in the years when the Romans dominated Western Europe.

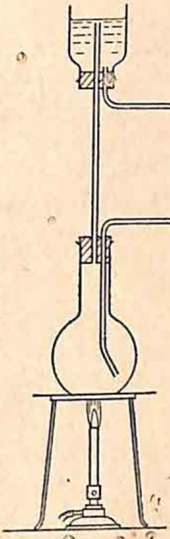

Fig. 137

## Modern central heating

Almost all large buildings and even some dwelling-houses are now heated by the central heating process, which can be followed by using the apparatus shown in Fig. 137.

*Expt. K.—To observe a working model of a central heating system.*

The apparatus is completely filled with water. While this is being done, note carefully how the two tubes connecting the flask to the cistern are arranged. The water in the flask is heated, and

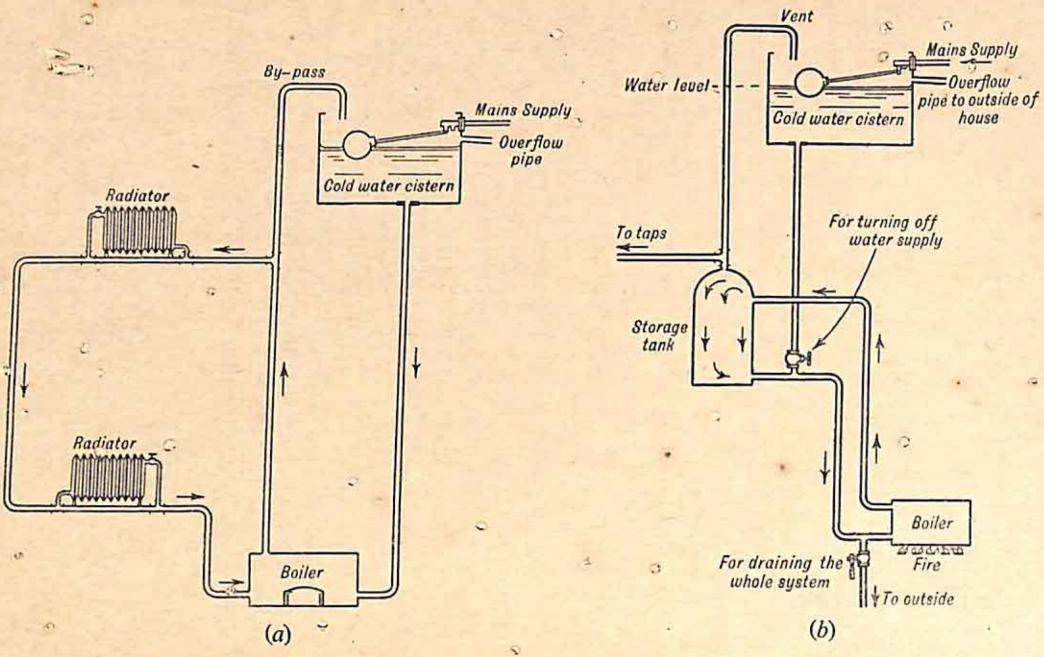

FIG. 138.—(*a*) Central heating system. (*b*) Domestic hot-water system

the course of the current followed by means of a little dye added to the cistern.

You should now compare this laboratory model with Fig. 138 (*a*), which shows the general arrangement in actual practice. Note that the system must always be full of water; this is arranged automatically by having permanent connection to the water mains, the flow of water being regulated by a valve operated by the float in the cistern. The outflow from the boiler does not go to the cistern as in the model, but has an "off-shoot" (by-pass) leading to it. This has an open end so that the air, dissolved in cold water, may be set free and not carried round with the warm water, out of which it has been driven. This open pipe also acts as a safety valve for the escape of steam if the water should be overheated. The temperature of the outflow from the boiler should be about 75°–80° C.

### Domestic hot-water supply

This is just a central heating system with a storage tank with leads to the kitchen and bathroom replacing the radiators. Compare Figs. 138 (*a*) and (*b*), noting in the second diagram:

(1) where hot water is fed into the storage tank;
(2) where cold water is fed from the cistern to the boiler;
(3) from where the hot water is drawn.

### The ventilation of mines

Every mine is now required by law to have at least two shafts. Formerly, ventilation was secured by having a fire burning at the foot of one shaft to produce a hot convection current up this shaft, and a cold current down the other one, a process of air circulation which is easily illustrated in the laboratory.

*Expt. L.—To observe a working model illustrating underground ventilation.*

Two lamp chimneys are mounted in the lid of a cardboard box and a small candle placed in the box, to be directly below one chimney, when the lid closes the box (Fig. 139). The candle is lit, the lid and chimneys replaced to cover the box, and the tracks of the cold and hot currents followed by holding a spill of smouldering blotting paper over the top of each chimney in turn.

Nowadays, this method is seldom used. Advantage is taken of the fact that the air in the mine passages is normally warmer than that above ground and the circulation is maintained by electrically driven fans, driving the warm air up one shaft and drawing the cool air down the other.

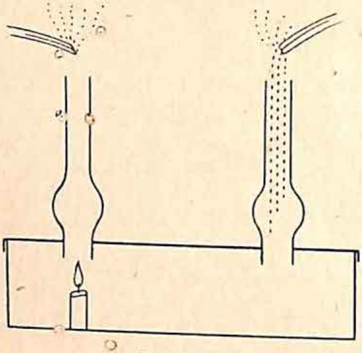

FIG. 139

## The absorption of radiation from a hot substance

If an object is placed in front of a glowing electric heater, it is warmed only by absorbing the radiation from the heater, because air is a very bad conductor of heat. The heat which is transferred by the heater to the air is rapidly carried upwards by the process of convection. When the radiation reaches a surface, does the absorption depend in any way upon the kind of surface used?

*Expt. M.—To examine the absorbing powers of different surfaces.*

A sheet of stiff, unglazed, white paper, about 1 ft. square, is treated (see footnote, p. 191) to render it sensitive to heat. On one side of it a circle about 3 in. in diameter is drawn and painted in with dead-black paint. Around this centre, a rim, about 1 in. wide, is drawn and painted in with aluminium paint.[1] The sheet of paper is then mounted on strips of wood (Fig. 140) and hung in front of a glowing electric radiator (750–1000 watts) (Fig. 141), with the painted side facing the radiator and about 15–18 in. distant from it. Observations on the unpainted side of the paper show that the part of it behind the black centre changes colour very rapidly, whereas that behind the aluminium rim is hardly affected at all. The remainder of the paper usually changes colour, but less rapidly and to a paler shade of blue than the centre spot. Which part of the paper receiving the radiation from the heater absorbed it (*a*) to the best extent, (*b*) to the poorest extent?

*Expt. N.—To examine the absorbing powers of different surfaces* (Alternative Expt.).

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[1] Alternatively, if available, a strip of silver paper may be pasted on this portion of the paper.

Several thermometers, alike in all respects, are selected. The bulb of one is thinly coated with lamp-black,[1] of another with black enamel, of a third one with white enamel and of a fourth with dead-white paint. (*Before proceeding further, the prepared surfaces must be dry.*) The thermometers are supported vertically, with their bulbs at the same height and at the same distance, about 12 in., in front of a cold electric heater. A screen is placed between the heater and the thermometers, and the electric current then switched on. When the heater is glowing, the screen is removed and the temperatures recorded by each thermometer are read every half minute.

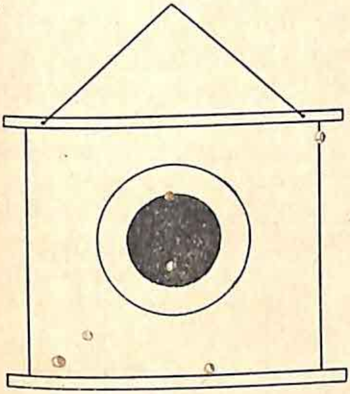


FIG. 140

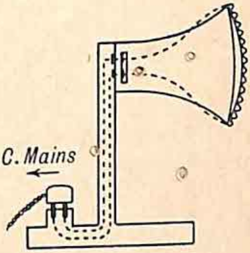


FIG. 141

Does the temperature rise at the same rate in each?

Which bulb absorbed most heat during the time of observation?

Which surface is the best absorber of heat?

Compile a list in order from the best absorber to the worst.

In the first of these experiments, each part of the paper, being equidistant from the heater, would receive radiation equally well, but the different surface coverings clearly did not absorb this radiation to the same extent. The same may be said respecting the surfaces of the thermometer bulbs. What becomes of the radiation which is not absorbed?

[1] The most effective way of doing this is to coat the bulb very thinly with varnish, and, when this is nearly dry, scatter finely powdered charcoal (lamp-black) all over the varnish. This gives a good, hard, permanent surface.

*Expt. P.—What happens to the radiation which falls upon a surface but is not absorbed by it?*

The lamp-blacked bulb B of a thermometer is mounted so that it is at the level of the heater, but slightly to one side, and is completely screened from the direct effects of radiation from the heater. A small chromium plated mirror is then suspended in front of the heater and turned at an angle of 45° (see *Fig.* 142). When the heater is glowing, the thermometer shows a rise of temperature, although it is screened from the direct effects of radiation. When the mirror is removed the temperature recorded by the thermometer falls. How did the bulb receive the radiation which it absorbed?

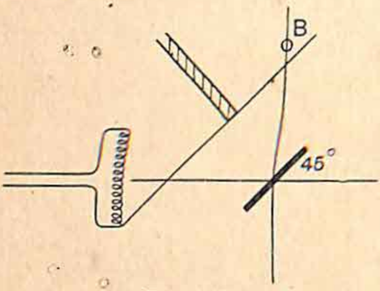


FIG. 142

## Radiation of heat

A body need not be red hot in order to send out radiation; any object which is warmer than its surroundings will do so. Does the radiating power of such a body depend, as does its absorbing power, upon the nature and colour of its surface? To answer this question, each radiating surface must be at the same temperature, and, to be certain of this, the highest convenient temperature is only 100° C.

## The ether thermoscope

With a radiator at a temperature as low as 100° C., the bulb of an ordinary thermometer, even if it is coated with lamp-black, is not a sufficiently sensitive absorber of the radiation which falls upon it. A new instrument, known as an ether thermoscope, must be used (Fig. 143). It is made of glass, the liquid is ether, coloured for easy observation, and the remainder of the space contains ether vapour, not air. The thermoscope, like the thermometer, is completely sealed. The lower bulb receives the radiation, and to improve its absorbing power, it is coated with lamp-black. The ether vapour in the upper part of this bulb responds to changes of temperature very much more readily than the liquid ether so that, for all purposes of observation, the liquid acts only as an indicator.

*Expt. R.—To compare the radiating powers of different surfaces.*

Radiating surfaces are compared by using Leslie's Cube. This is a cubical "tin" box, the sides of which are prepared for testing by coating them respectively with (*a*) lamp-black, (*b*) black enamel, (*c*) dead-white paint and (*d*) a little mercury to get a highly polished metal surface. A screen is erected between the cube and a boiler from which steam is to be blown into the cube, and the thermoscope is mounted with its black bulb opposite the middle of the face of the cube farthest from the boiler (Fig. 144). Steam is then passed into the cube, and when the level of the ether in the stem of the thermoscope is stationary, its position is marked by a tab of paper, labelled according to the surface being tested.

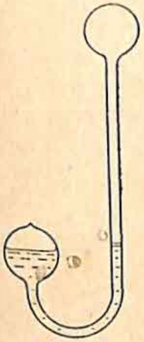


FIG. 143

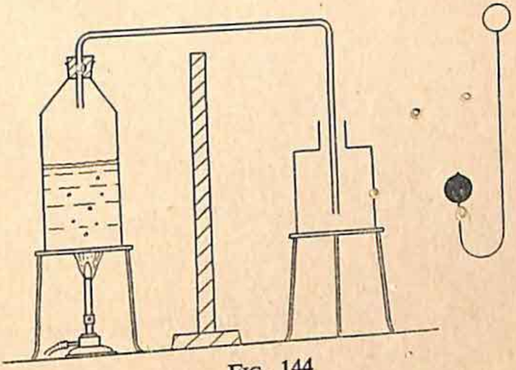


FIG. 144

This process is then repeated successively for the other faces, the cube being turned each time through a right angle, the distance between face and bulb being kept constant. The order of the tabs from highest to lowest gives, at once, the order of radiating power for the surfaces tested. As far as possible, this order should be compared with that compiled when testing absorbing powers.

**Summary of results**

(1) Dull or rough surfaces are better radiators (or absorbers) than polished ones.

(2) A dark coloured surface is a better radiator (or absorber) than a light coloured one.

(3) A good radiator is a good absorber (and vice versa).

(4) A good radiator is a bad reflector (and vice versa).

## Some general applications using all the processes of transmission of heat

*The miner's safety lamp.*

*Expt. S.—To observe the control of an explosive mixture of coal-gas and air.*

A cocoa-tin, with a well-fitting lid, has a half-inch hole cut in its base and an eighth-inch hole in the lid. The tin is charged with coal-gas. After time has been allowed for the expulsion of the air, the coal-gas is lit as it escapes through the lid-hole (Fig. 145 (*a*)). The gas-tap is turned off and the tube removed. The flame gradually dies down, and when it is very low there is an explosion which removes the lid. It is replaced, covered with a sheet of fine copper gauze, and the experiment is repeated (Fig. 145 (*b*)). This time, the flame dies away without any explosion.

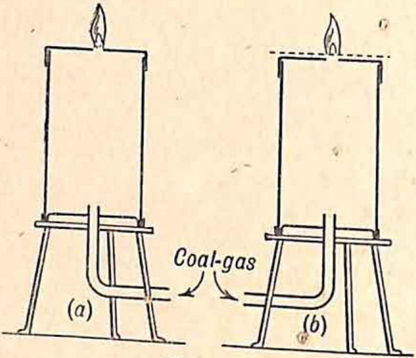


FIG. 145

As the gas burns, air flows into the can, and if the mixture of gas and air near the exit reaches a certain temperature, the flame "back-fires" and the explosion occurs. Copper is a very good conductor of heat; consequently, heat from the flame is conducted rapidly away from the exit through the strands of the gauze which thus exposes a relatively large warmed surface to the air. This surface loses heat by radiation at a rate sufficient to keep the temperature of the mixed gases at the exit low enough to prevent a "back-fire" and consequent explosion.

In coal mines, quantities of a gas called fire-damp, one of the constituents of ordinary coal-gas, are sometimes present in the air. It is consequently unwise ever to expose a naked flame in most mines. In collieries where oil lamps are still in use, the flame is enclosed in a cylinder of copper gauze, which, in the manner described above, prevents the mixture of air and fire-damp outside from catching fire and exploding. But air must be continuously admitted to the lamp to keep the flame burning, and this air will carry fire-damp in with it. Why does this mixture not explode inside the cylinder? Carbon dioxide, a gas which does not support combustion, is produced by the burning of the oil, and the presence of a small quantity of this gas near the flame prevents explosion. The fire-damp just burns quietly in the air, and, if the flame be turned low, the presence of this highly dangerous gas is at once shown by the pale blue cap above the yellow oil-flame.

*The tropical explorer's pith-helmet.*—A light framework in the form of a helmet within a helmet is constructed of bamboo, and each part is covered with white drill. The space between the drill covers is filled with dried, powdered pith. The whole helmet fits on to the head by means of a corrugated band, and the crown has a hole at the top covered by a metal cap which can be adjusted (Fig. 146). The white cover is a good, but not perfect, reflector of the sun's radiation; what it does absorb is conducted very badly through the pith, amongst which are thousands of tiny air pockets. The corrugations in the band and the hole in the crown provide adequate ventilation whilst the helmet is being worn.

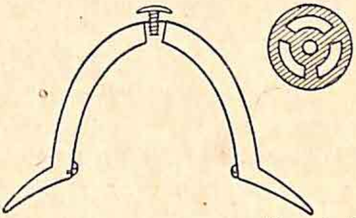


FIG. 146.—Pith-helmet

The whole thing may look cumbersome, but it is extremely light in weight and astonishingly effective in protecting the head against the fierce radiation of the tropical sun.

*The vacuum flask.*—This is a double-walled glass vessel shown in section in the diagram (Fig. 147). The outer surface of the inner wall and the inner surface of the outer wall are thinly silvered, as much as possible of the air between these walls is extracted, and the outer wall sealed up. The flask is closed by a cork or rubber stopper. Glass being a bad conductor, very little heat is conducted to or from the top of the vessel, and there is only a trifling loss due to convection inside the flask because it is closed by a bad conductor. Conduction and convection play no part in transferring heat from the inner to the outer wall; and, further, these are silvered so that their surfaces will be bad radiators and good reflectors. It is therefore equally difficult for heat to pass into or out of the vessel; thus, the flask is equally effective for the storage of cold or hot liquids. In fact, this type of flask was designed by Dewar, in 1892, for the purpose of storing liquid air, the temperature of which is about 190° C. below zero.

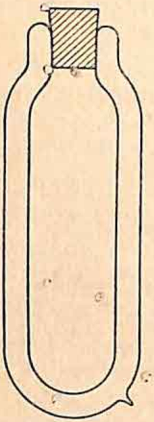


FIG. 147.
Vacuum flask

## The school "radiators"

Heat is conducted from the hot water flowing from the boiler (p. 198) through the iron pipes, from which it is transmitted to the room. Some of course will be radiated, but we must not overlook the air in contact with the pipes. This air receives heat by conduction, and so must rise by convection to the higher parts of the room. Of the heat contributing to the comfortable temperature of the room, about four-fifths is due to the circulation of the air by convection currents. The remaining fraction, due to radiation, is relatively so small that it is not necessary to have the pipes painted black. Further, since the fraction contributed by radiation is so small, you will appreciate that the term "radiator", though still in general use, is not a good one in a scientific sense.

# APPENDIX A

## *Calculation of Areas*

*Rectangle*

Area $=$ length $\times$ height

*Triangle*

$$\text{Area}=\frac{\text{base}\times\text{altitude}}{2}$$

*Circle*

$$\text{Area}=\frac{22}{7}\times(\text{radius})^2$$

Usually written $\pi r^2$

*Cylinder*

(*a*) Curved surface *only*

$$\text{Area}=2\pi\times\text{radius}\times\text{height}$$
$$=2\pi rh$$

(*b*) Total surface

$$\text{Area}=2\pi rh+2\pi r^2$$

*Sphere*

$$\text{Area}=4\pi\,(\text{radius})^2$$
$$=4\pi r^2$$

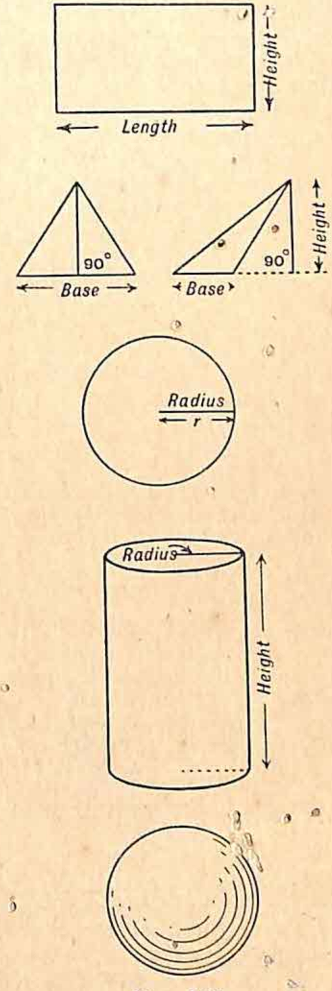
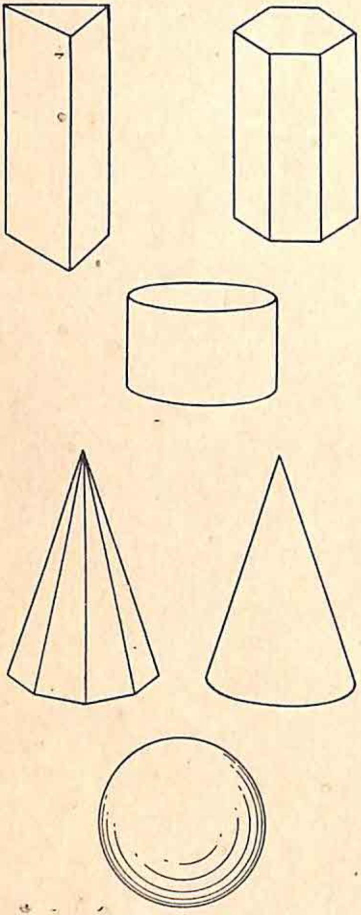


FIG. 148

## *Calculation of Volumes*



*Right prisms* (including cylinder).

Volume = area of base × height.

*Pyramids* (including cone).

$$\text{Volume} = \frac{\text{area of base} \times \text{height}}{3}$$

*Sphere.*

$$\text{Volume} = \frac{4}{3}\pi\,(\text{radius})^3$$
$$= \frac{4}{3}\pi r^3$$

FIG. 149

*The balance.*—A student's chemical balance (Fig. 150) is a delicate and relatively expensive instrument; it should always be used with great care. Do not call it a pair of scales! If an old balance is available, it should be taken to pieces and the parts examined in the following manner:

(1) Remove the pans PP (preferably made of bakelite) together with their framework.

(2) Take off the stirrups SS from which the pans hang.

(3) Lift off the beam BB. If you examine this you will see three agate knife-edges, one in the centre, about which the beam turns when the balance is in use, and one at each end, from which the pans are suspended. You should also notice the pointer I, and the adjusting screws at the ends of the beam. The beam rests on the supports RR when the balance is not in use, so that there is no weight on the knife-edges in this condition.

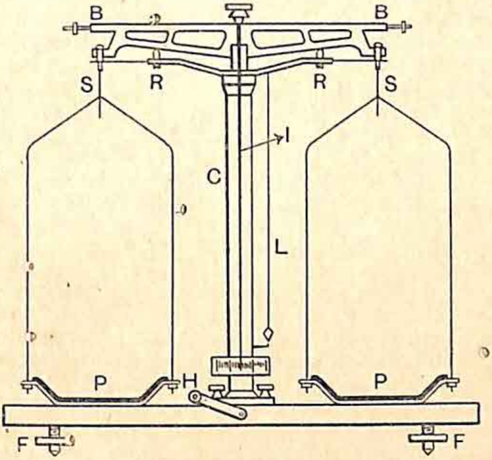


FIG. 150

(4) Turn over the handle H. This raises a rod inside C. When the balance is in use, the flat agate surface at the top of this rod lifts the beam by the central knife-edge; the balance is free to swing and the pointer I moves across the scale.

(5) The feet FF, two in front and one at the back, can be adjusted so that the plumb-line L shows that the balance is level.

The central knife-edge is exactly midway between the outer knife-edges, and when the balance is properly adjusted the pointer should swing an equal number of divisions each side of the zero mark. If objects of equal weight are placed in the pans, i.e. they are suspended from the outer knife-edges, the balance will still be adusted. In weighing, an object is put on one pan (usually the left) and weights are added methodically to the other until the pointer swings equally on each side of the centre of the scale.

*Weights.*—Boxes of weights differ, but the larger weights are usually made of brass, the fractions of aluminium. The best arrangement of weights (in grams) is the following:

| | | | |
|---|---|---|---|
| 50 | 20 | 10 | 10 |
| 5 | 2 | 1 | 1 |
| 0·5 | 0·2 | 0·1 | 0·1 |
| 0·05 | 0·02 | 0·01 | 0·01 |

Fraction weights are often marked in milligrams. Thus, 500 mg. = 0·5 gm. If it is necessary to weigh to three places of decimals, a rider is needed. This is a suitably shaped piece of aluminium wire weighing 0·01 gm. It can only be used on a balance each half of the beam of which is divided into 10 parts. If the rider is placed on division 5, it is equivalent to a weight in the pan of $5/10 \times 0{\cdot}01 = 0{\cdot}005$ gm. The actual number on the beam over which the rider rests is the third decimal place figure.

*Balance rules.*—(1) Stand or sit immediately in front of the balance. Only one person can weigh at a time.

(2) See that the balance is clean, and check your box of weights. Turn the handle H carefully, so that the balance swings, and see if it is adjusted. A slight error in adjustment does not matter, since all weights are found by difference. If there is anything wrong, or if you have an accident, report at once to whoever is in charge. Do not try to adjust a balance yourself.

(3) Never put anything hot or wet on a balance pan. Never put any chemical directly on to a pan. Even metals like zinc and copper must be weighed on watch-glasses.

(4) Place the *object* to be weighed on the *left pan*, the box of weights in front of, and the *weights* on, the *right pan*. (If left-handed the reverse.)

(5) *Lift the weights with the forceps*, not with the fingers.

(6) Raise and lower the beam gently, and *do not add or remove weights when the beam is swinging*. This is necessary to prevent damage to knife-edges, which must be sharp if the beam is to turn easily.

(7) Begin with a weight which you think is too large. At first, raise the beam slightly so that you can see how the pointer is going to move. Having found a weight which is too large, work down through the box in order. Never choose weights at random.

(8) Arrange the weights neatly on the pan, the larger weights across the centre, and the fractions in front.

(9) When the pointer swings as nearly as possible an equal number of scale divisions on each side of the centre, add up the weights on the pan. Write down the weight in your book at once. Check the weight by means of the empty spaces in the box. Remove the weights from the pan into the box, in order and into the proper places, again checking the weight.

(10) When you have finished weighing, close the balance case and the box of weights.

*The use of an electric immersion heater for introductory experiments in calorimetry.*—A 250-watt commercial electric immersion heater (as supplied by Messrs. Belling & Co., Enfield, Middlesex) provides a steady supply of heat for introductory calorimetry experiments. It should be immersed in about a quart (rather more than a litre) of water, contained in a beaker about 30 cm. tall and 10 cm. diameter, in order to obtain a convenient rate of temperature rise. It may be used advantageously to show, for example, that

(*a*) the same quantity of heat will produce the same temperature rise in a given weight of water, irrespective of the initial temperature;

(*b*) the temperature rise produced by a given quantity of heat is inversely proportional to the weight of water used.

# APPENDIX B

*To obtain a steady stream of chlorine* (p. 65)

Drop 10 gm. of solid, commercial potassium permanganate into a 500-c.c. flask. Fit this with a cork carrying a tap-funnel and a delivery tube bent at right angles. Add concentrated hydrochloric acid from the tap-funnel, drop by drop, to the potassium permanganate. Chlorine is evolved at first without heating.

TABLE OF THE COMMONER ELEMENTS

| Element | Class | Symbol | Combining power or valency |
|---|---|---|---|
| Aluminium | Metal | Al | 3 |
| Calcium | Metal | Ca | 2 |
| Carbon | Non-metal | C | 4 |
| Chlorine | Non-metal | Cl | 1 in chlorides. |
| Copper | Metal | Cu | 2 |
| Hydrogen | Non-metal | H | 1 |
| Iodine | Non-metal | I | 1 in iodides. |
| Iron | Metal | Fe | 2 in ferrous compounds.<br>3 in ferric compounds. |
| Lead | Metal | Pb | 2 |
| Magnesium | Metal | Mg | 2 |
| Mercury | Metal | Hg | 2 |
| Nitrogen | Non-metal | N | 3 in ammonia. |
| Oxygen | Non-metal | O | 2 |
| Phosphorus | Non-metal | P | 5 in phosphorus pentoxide. |
| Potassium | Metal | K | 1 |
| Silver | Metal | Ag | 1 |
| Sodium | Metal | Na | 1 |
| Sulphur | Non-metal | S | 2 in sulphides. |
| Tin | Metal | Sn | — |
| Zinc | Metal | Zn | 2 |

# APPENDIX C

*Derivations of uncommon words used in biology*

Aerobic: Gk. *aer*=air, *bios*=life.
Anaerobic: Gk. *a-* or *an-*=without, plus the above.
Amœba: Gk. *amoibē*=change.
Biology: Gk. *bios*=life, *logos*=discourse.
Cell: Lat. *cella*=small compartment.

Chlorophyll: Gk. *chloros*=green, *phyllon*=leaf.
Chloroplast: Gk. *chloros*=green, *plastos*=moulded.
Corpuscle: Lat. *corpusculum*=a very small body.
Cytoplasm: Gk. *kytos*=cell, *plasma*=anything formed.
Nucleus from diminutive of Lat. *nux*=nut, meaning kernel.
Ovary: Lat. *ovum*=egg.
Protoplasm: Gk. *protos*=first, *plasma*=anything formed.
Spirogyra: Gk. *speira*=coil, *guros*=a circle.
Vacuole means a minute cavity, not a vacuum.

### *Material*

All forms of biological material can be obtained from The Biological Supply Company, Rhydyfelin, Aberystwyth.

T. Gerrard & Co., 46–48 Pentonville Rd., London, N.1, or Flatters and Garnett, 309 Oxford Rd., Manchester, supply frogs, models, mounted or unmounted skeletons, biological specimens and microscope slides.

H. Darlaston, 31 Freer Rd., Birchfield, Birmingham, supplies prepared slides or will mount the customer's own material.

Hugh Newman, 42 Salisbury Rd., Bexley Heath, Kent, supplies all stages of butterflies and moths, entomological collectors' apparatus, mounting boards, pins, setting boards.

### *To examine an animal cell and a plant cell*

Scrape the inside of your cheek with a glass spatula, and place the scrapings on a microscope slide together with a drop of acetic acid solution (1 per cent). Put a cover-slip over the material and search for cells with $\frac{1}{3}$ in. objective in light which is not too intense. Finally, examine under $\frac{1}{6}$ in. objective.

Break an iris leaf across at the base, and skin upwards from the break. Examine a very thin strip of the clear skin, mounted in acetic acid as above, under $\frac{1}{3}$ in. objective.

### *To examine Amœba*

Allow the tube of material as purchased to settle. Remove a *very small* portion of the sediment with a suitable device, e.g. a pen-filler, and transfer to a microscope slide. Cover with slip; search and examine with $\frac{1}{3}$-in. objective. To show the nucleus, irrigate with 1 per cent acetic acid (i.e. place a drop of the acid against one edge of the slip and draw off water from the opposite side with filter-paper).

### *Dissection of a frog to show internal organs*

Kill the frog by dropping it into a 500-c.c. beaker containing a wad of cotton wool soaked in chloroform. Cover with a heavy wood block and leave for 15 minutes after all struggles cease.

Place the frog on its back in a dissecting dish and pin out the arms and legs in extended positions. Lift the loose skin away from the body wall, cut it through from legs to head and pin out as in the figure (p. 92). This exposes the muscles of the body wall, in which can be seen a thin blue line, the anterior abdominal vein. Make careful incisions in the muscular wall on either side of this, push a pair of fine pointed forceps underneath the vein from one incision to the other, and with them pull a loop of cotton under the vein. Cut the loop, and with the two pieces of cotton tie the vein securely in two places about a quarter of an inch apart. Cut through it between the two ligatures, thus avoiding bleeding. In subsequent operations avoid further cutting of this vein.

Now carefully cut away the muscular wall of the body, taking care not to damage the organs beneath with the scissors. Lift the pectoral girdle slightly, and cut through it with a strong pair of scissors, avoiding damage to the heart. The arms can now be pinned out more widely, and the lungs and heart exposed, in addition to the lower organs.

### *Preparation to show external muscles of a frog*

Kill the frog with chloroform as above. Lift the skin on the ventral surface and cut a slit with a pair of fine-pointed scissors. Cut through the skin in a complete circle round the body in the region of the arm-pits. At the arm-pits themselves a blood vessel should be avoided to obviate bleeding. Hold the upper part of the body in one hand, seize the skin of the lower part in the other and pull. The skin of the lower parts can be pulled away as a whole, revealing the external muscles. The gastrocnemius or calf muscle is particularly well shown, and can be easily detached by cutting through its tendon where it passes round the heel. The nerve supplying it (sciatic) can be seen as a white thread embedded in the tissues just above the knee.

### *Suggestions for an elementary demonstration with a sheep's heart*

The names "right" and "left" are applied to the heart as it is in the body. Diagrams of the heart in connection with the circulation usually show it as if in a person facing the observer, i.e. the right side of the heart is on the observer's left.

Obtain a heart which has an undamaged surface. Careless butchering often leads to a deep cut on the front. If possible get one which has not had the arteries and veins cut off too closely. Grooves filled with fat on the back and front indicate the line of partition between the ventricles (see Figs. 151, 152). Press the wall of each ventricle between the thumb and finger. The one which is the more easily deformed is the right ventricle. Place the heart facing you so that this is on your left. The appearance will be as in Fig. 151. The auricles appear as rather flat fleshy flaps, but they can be distended by pouring in water.

Using a blunt wooden penholder as a probe, endeavour to identify the chief arteries and veins. The arteries, being more muscular, will have retained their shape, while the less muscular venous walls are usually in a collapsed state, with their openings partly masked. The aorta opens directly into the left ventricle through a valve, while the pulmonary arteries similarly give directly into the right ventricle. The veins, however, open directly into auricles, which then, through valves, connect with the ventricles. The pulmonary veins enter the left auricle, while the veins from the general circulation (the venæ cavæ) enter the right auricle.

Cut away sufficient of each auricle to show the openings into the ventricles. Fill the ventricles with water and squeeze gently. This brings the valves into action, and they can be seen to float up and block the entrances, thus preventing water from flowing back into the auricles. Open the right ventricle by cutting as indicated by the thick unbroken line in Fig. 151, taking care not to make the incision deep enough to injure the septum between the two ventricles. The valves can now be seen to consist of flaps or cusps with cords attaching them to the walls of the ventricle. The cords prevent the valves from being turned inside out by the pressure of the blood. From their shapes,

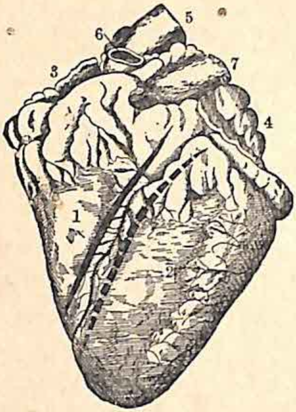


FIG. 151.—Front of sheep's heart

1, right ventricle; 2, left ventricle; 3, right auricle; 4, left auricle; 5, aorta; 6. cut branch of the aorta; 7, pulmonary artery. To open the right ventricle cut down the thick unbroken line. To open the left ventricle cut along the thick dotted line. Between these lines the groove containing a blood vessel marks the position of the partition between the two ventricles.

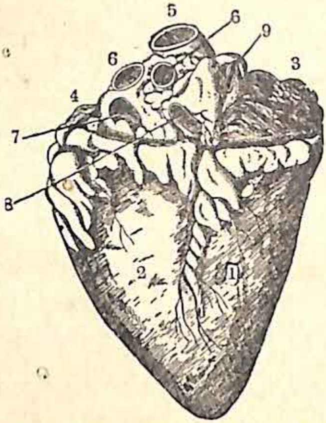


FIG. 152.—Back of sheep's heart

1, right ventricle; 2, left ventricle; 3, right auricle; 4, left auricle (small portion only is visible); 5, aorta; 6, the pulmonary arteries; 7, trunk of pulmonary vein; 8, vena cava inferior; 9, vena cava superior.

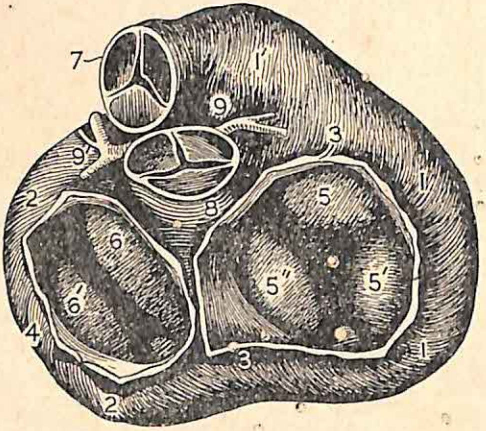


FIG. 153.—The base of the heart

The auricles have been cut away, and the valves are closed. 1 and 1′, right ventricle; 2, left ventricle; 3, wall of right auricle; 4, wall of left auricle; 5, 5′ and 5″, tricuspid valve; 6 and 6′, the mitral valve; 7, pulmonary artery; 8, aorta; 9, small arteries that supply blood to the heart itself (coronary arteries).

the valves at the exits of the left and right auricles are called the mitral (like a bishop's mitre) and tricuspid (three cusps) valves respectively (see Fig. 153).

A similar arrangement of valves closes the exits of the heart to the aorta and the pulmonary artery. Cut the aorta off close above the valve. The action of the valve can be seen by pouring a little water into the three cusp-like pouches, which then bulge out and close the way back into the heart. Cut down the pulmonary artery between the cusps of the valve laying the vessel open so that the little pouches can be seen as in Fig. 154. The valves at the exits to the aorta and the pulmonary artery are called "semilunar" valves from the half-moon shape of their cusps. A small opening in each of two of the valve pockets of the aorta may be noticed. This leads to the small arteries (coronary arteries) which supply blood to the heart itself (Fig. 153).

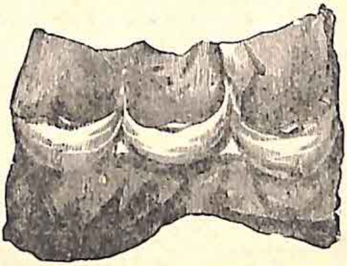


FIG. 154.—Pulmonary artery cut downwards to show the semilunar valves

Finally, cut open the left ventricle by an incision as indicated by the thick dotted line in Fig. 151. Note the much greater thickness of its walls compared with the right ventricle. An arrangement of cords from the valve leading from the auricle can be seen. They are similar in function to those in the right ventricle, but are thicker and stronger. The left ventricle is longer than the right ventricle and forms the apex of the heart.

# QUESTIONS

## CHAPTER 1

1. State the important differences between solids, liquids and gases, and classify the following substances: diamond, treacle, sand, putty.

2. Name the instruments you would use to measure, as accurately as possible, the following volumes of water, 25 c.c., 18·7 c.c., 357 c.c.

3. If you had to measure a litre of water as accurately as possible would you use a graduated cylinder or a litre flask? Give reasons for your answer.

4. Can you convert an ordinary garden watering-can into an overflow jar? Describe carefully what you would do.

5. Write down, in order, all the weights that would be used with a chemical balance when weighing a body of (*a*) 87·1 gm., (*b*) 13·36 gm. Cross out all those weights returned to the box during the process.

6. From the same sheet of cardboard a circle of 10 cm. radius and a square, side 10 cm., are cut out. The square weighs 3·5 gm. What do you expect the circle to weigh?

## CHAPTER 2

1. Which is heavier, a ton of bricks or a ton of feathers? Explain.

2. A piece of wood floats in water and sinks in methylated spirits. If the density of the latter liquid is 0·82 gm. per c.c., what do you know about the density of the wood?

3. A sufficient number of nails is driven into a rectangular block of wood so that it floats in pure water with its top surface level with the water-surface. What will happen when as much salt as possible is dissolved in the water?

4. In what way do the statements made in the experiments on pp. 14–15 need modifying for floating bodies?

5. Why should a swimmer, when resting, float with his head well back in the water?

6. An iceberg floats in water. What happens to the volume of a quantity (say 1 cu. ft.) of water when it freezes completely? Explain how you arrive at your answer.

7. Will a ship draw more water in the Mediterranean Sea or in the docks at the Manchester end of the Ship Canal? Explain fully.

8. If you can just support a lump of iron when it is in water, what will happen if you try to withdraw it?

In the following problems, the values for densities, when needed, may be taken as follows:

| | | | |
|---|---|---|---|
| Brine | 1·2 gm. per c.c. | Mercury | 13·6 gm. per c.c. |
| Alcohol | 0·8 gm. per c.c. | Lead | 11·2 gm. per c.c. |

9. A lump of metal weighs 528 gm., and when immersed in water in a large overflow jar expels 60 gm. of water. Calculate its density.

10. When 50 c.c. of water are mixed with 50 c.c. of alcohol, the resulting liquid occupies only 96 c.c. What is its density?

11. A sealed, hollow glass bulb weighs 110 gm. in air and 10 gm. in water. What is its volume?

What will be the result if you try to weigh it in brine?

12. A large can containing water stands on the pan of a compression spring balance which reads 820 gm. A block of wood of weight 90 gm. is placed in the can. What does the spring balance now register? Does it matter whether the wood floats or not? Give reasons.

13. Will a solid lead sphere float in mercury? Explain fully.

14. A solid c.c. of gold weighs 19·2 gm. A gold chain weighs 48 gm. in air and 45 gm. in water. Find the volume and density of the chain. Can you make any further statement about the chain?

15. A floating body displaces 22 c.c. of water. What is the weight of this body and what volume will it displace when floating in a liquid of density 1·10 gm. per c.c.?

16. In problem 4, p. 18, the body floating in water displaced 18 c.c. When completely immersed it displaced 21 c.c. If attempts are made to float this body in oil of density 0·82 gm. per c.c., will they succeed? Give reasons.

17. If the simple, cylindrical hydrometer made in Expt. 5, p. 20, is 12·5 cm. long and it floats in water with 11·25 cm. of its length immersed, prove that it is unsuitable for use with liquids of density less than 0·90 gm. per c.c.

## CHAPTER 4

1. When a thermometer is suddenly plunged into a hot liquid, the mercury level in the stem falls before it rises. Why?

2. Why is it necessary to decide on *two* fixed standards of temperature before we can construct a temperature scale?

3. Use the graph you obtained in the experiment on p. 34 to change the following Centigrade temperatures: (*a*) 40, (*b*) 80, (*c*) 5, (*d*) 35, (*e*) 48, (*f*) 57·5, to their corresponding values on the Fahrenheit scale.

4. As in question (3), use your graph to convert the following Fahrenheit temperatures: (*a*) 68, (*b*) 167, (*c*) 140, (*d*) 98·4, (*e*) 77, (*f*) 154, to their corresponding values on the Centigrade scale.

5. Can you suggest what to do with your graph if you had to convert temperatures below freezing-point or above boiling-point?

6. If the temperature as recorded by a Centigrade thermometer rose from 15° to 60°, through what range would the mercury of a Fahrenheit thermometer rise for the same conditions?

7. Find by calculation the Fahrenheit temperatures which correspond to (*a*) 50° C., (*b*) 25° C., (*c*) 62·5° C.

8. A freezing mixture such as that used in Hope's apparatus (p. 49) has a temperature of 0° F. What would be the value on a Centigrade thermometer?

9. A clinical thermometer should always be cleaned after use. Is it wise to use boiling water? Explain.

10. Criticize the statement, "A red-hot coal is at a greater heat than a cup of boiling water".

## CHAPTER 6

1. Make a list of solids commonly used at home which dissolve in water. For what purposes are their solutions used?

2. Describe how you would attempt to remove (*a*) a grease-spot from your coat, (*b*) oil-paint from your hands, (*c*) dirt which is sticking to the wax polish on linoleum.

3. How would you find out whether a sample of soil from the garden contained soluble matter?

4. How could you obtain water fit to drink from sea-water? Draw a diagram of the apparatus you would use and explain how the water you would obtain differs from sea-water.

5. Find the solubility of A at 15° C., if 20 gm. of a saturated solution of A, made at this temperature, gave 3 gm. solid A by careful evaporation.

6. 25 gm. of solid B just saturate 100 gm. of water at 50° C. How much solid would be obtained by evaporating 25 gm. of a saturated solution made at 50° C.?

7. At 20° C., 1·5 gm. of Y saturate 10 gm. water, 1·8 gm. of X saturate 15 gm. water, and 3·6 gm. of Z saturate 20 gm. water. Arrange the solids X, Y, Z in order, beginning with the most soluble.

8. Explain how air gets into the radiators in a hot-water system.

9. What do you know of the connection between solutions and (*a*) mending a puncture in a tyre, (*b*) treating a sore throat?

10. Try to explain the difference between a disinfectant and an antiseptic. Name solutions which are used as disinfectants and antiseptics.

## CHAPTER 7

1. Is tobacco-smoke a solid or a gas? How do you explain the "disappearance" of smoke issuing from chimneys?

2. Give an account of the physical properties (see p. 62) of the following: coal, copper, petrol, glycerine, coal-gas.

3. Air is a mixture of two elements and not a compound. What is meant by this statement?

4. What kind of change takes place when (*a*) an electric current is passed through the filament of a lamp, (*b*) an electric spark is passed through a mixture of petrol vapour and air? Give reasons for your answer.

5. What are the chief elements found in living matter? State from what sources we obtain our supplies of these elements.

## CHAPTER 8

1. What tests would you apply to an object in order to find out whether it is alive? Why is it incorrect to call glass a dead material?

2. Briefly outline the functions of the following: (*a*) the contractile vacuole, (*b*) the sense organs of an animal, (*c*) the nucleus of a cell, (*d*) muscle, (*e*) the branches of a tree.

3. A fairly well known living organism has green leaf-like parts, but appears to get its food by catching flies. Would you group it as an animal or a plant? Give reasons for your answer.

What additional observations on the organism would be helpful in settling to which group it belongs?

4. In what respects do Amœba and Spirogyra illustrate the differences between animals and plants?

Compare the methods of reproduction of the two organisms.

## CHAPTER 9

1. State which parts of a flowering plant (*a*) take in food, (*b*) give out waste products, (*c*) help to keep the plant upright and in position, (*d*) attract insects, (*e*) are concerned with the production of fresh plants.

2. A gardener gives you (1) an artichoke tuber, and (2) what he calls a montbretia "bulb". Describe how you would examine them in order to find out whether (1) was a root tuber or a stem tuber, and whether (2) was a bulb or a corm.

3. Draw a vertical section through the middle of a single bloom of the wallflower, and name the various parts as neatly and clearly as possible.

4. State briefly the different ways you can think of by which (1) animals, (2) plants, manage to survive the hard times of winter.

5. Mention, with a brief description of each, as many parts of plants as possible which can be set to give us fresh plants.

## CHAPTER 10

1. Why is it an advantage to sort living things into groups or classes? Give three examples each of invertebrate and vertebrate animals.

2. What parts are played by (*a*) the male frog, and (*b*) the female frog in the production of frog spawn? What is the food of the tadpole (*a*) immediately after hatching, (*b*) during most of its life, (*c*) when it is about to turn into a frog?

What are its methods of breathing at the above three stages?

3. A frog will drown if it cannot get out of water, yet it can remain alive under water for quite a long time. Suggest an explanation of these facts.

4. What are the duties of (*a*) the liver, (*b*) the stomach and intestines, (*c*) the tail of the tadpole, (*d*) the tongue of the frog, (*e*) the heart?

5. Explain the meaning of the following: (1) vertebrate, (2) invertebrate, (3) fertilization, (4) gills, (5) hibernation.

6. Describe the main changes which take place in the appearance of a tadpole from the time of hatching until the young frog leaves the water.

## CHAPTER 11

1. Mention (*a*) bones in two different regions of the body which are used to protect delicate parts, and (*b*) two different bones which are used in producing movement. Explain in each case how they fulfil these functions.

2. Give a simple description of the arrangement of bones in the hand and arm, and point out how it differs from the arrangement in the foot and leg.

3. Draw diagrams to illustrate as clearly as possible the following cases of the use of muscles and bones: (*a*) to produce a rapid movement of part of a limb, (*b*) to exert a very powerful force.

4. Compare the arrangement of bones in the trunks of a frog and of man, pointing out the points of resemblance and of difference.

5. What are the functions in man of the following: (*a*) the collar bone, (*b*) the small bones of the wrist, (*c*) the discs of cartilage between the vertebræ, (*d*) ligaments, (*e*) tendons.

6. What is the difference between a broken hip and a dislocated hip? How are dislocations of the bones prevented from occurring frequently?

Illustrate by a diagram the structures present at the joint between two bones.

## CHAPTER 13

1. A man carrying an accumulator thinks that he has spilt some of the liquid it contains on his coat. What is this liquid? How can he find out whether there is any of the liquid on his coat? What will happen if it is left in contact with the cloth?

2. When certain insects sting, e.g. ants and bees, they inject formic acid into the flesh. What substances commonly found at home can be used to treat such a sting? Explain what happens when they are applied to the sting.

3. Sour fruit is sold in "tins" which are made of sheet iron coated with tin. Explain why iron only cannot be used. Suggest a better material for the container and say why you select it.

4. The liquid contained in the human stomach contains hydrochloric acid. Indigestion is sometimes due to excess acid, and milk of magnesia is said to be a remedy. To what class of substances do you suggest this milky liquid belongs? How would you find practically (two experiments) whether your suggestion was correct or not?

5. Spinach contains oxalic acid which is poisonous, yet spinach is used as as a vegetable. Explain why this is possible.

6. What is (*a*) a mineral, (*b*) a mineral acid, (*c*) a mineral water?

## CHAPTER 16

1. Name two compounds which are gases, which you could obtain by burning elements in oxygen. By what properties would you recognize each of these gases?

2. What is an oxide? What would you expect to see when a phosphorus bomb explodes? Explain your observations. These bombs have been used in warfare; why?

3. State exactly how you would lay and light a coal fire. Give reasons for all that you do.

4. State and explain the measures you would adopt (*a*) to keep a fire alight for a long period without attention, (*b*) to make a dull fire burn brightly.

5. A large tank of petrol is on fire. Explain what would happen if streams of water from ordinary hoses were used to try to extinguish such a fire.

6. Why is it dangerous to carry loose potassium chlorate throat-tablets in the same pocket as a box of "safety" matches?

7. Explain exactly what would happen if a mouse were kept in a wire cage near the top of a closed bell-jar, which is standing in a trough containing lime-water.

8. Give an account of the connection between (*a*) oxygen, (*b*) nitrogen, and living things.

## CHAPTER 17

1. What reasons have we, both from direct observations and from the structure of the blood vessels, for thinking that the blood circulates, and does not merely surge backwards and forwards?

Man is said to have a double circulation. Explain what is meant by this.

2. Name the three kinds of blood-carrying tubes in the order of the thickness of their walls. Show how these different thicknesses suit the duties which the tubes perform.

3. How would observation of the blood flowing from a cut tell you whether it was likely to cause a dangerous loss of blood? Explain the correct ways of dealing with dangerous bleeding.

4. Why does the left side of the heart differ (*a*) in thickness and (*b*) the colour of its blood, from the right side?

Explain how the colour of the blood varies in the different parts of the blood circuit, and state the reasons for the differences.

5. Show the relation between the constituents of blood, plasma and serum.

What do you imagine would be the effect on an animal if it were possible at a given moment to destroy (1) its red corpuscles, (2) its white corpuscles? (Consider the two cases separately, and state roughly what *time* you think would be necessary for the effects to show.)

6. Point out an important difference between the heart of man and that of a frog. Give any reason you can for considering the arrangement in man to be more efficient than that in the frog.

## CHAPTER 18

1. Compare the methods by which oxygen is obtained from the air and distributed round the body in the cases of (*a*) man, (*b*) frog, (*c*) earthworm, (*d*) an insect.

2. What reasons can you suggest which explain why blood is unnecessary to Amœba? Why is it very unlikely that anyone will ever discover a new type of Amœba, which has no blood system, yet which grows as big as a cricket ball?

3. Explain the ways in which we bring about the exchange of gases between our lungs and the air. For what reasons connected with respiration is a wound in the chest-wall dangerous?

4. Explain how a dog gets cool quickly when it is overheated. By what methods do we lose heat?

Why is it easier to keep cool on a day when a laundress can dry her clothes quickly out of doors, than on one in which the drying is slower, though the temperature in the first case may actually be higher than in the second?

5. How would you show that the respiration of green plants is a similar process to the breathing of animals as regards its effects on the air? What precaution must be taken in experiments on the respiration of plants, and why?

## CHAPTER 19

1. Why is *water* used in a motor car to keep the engine cool?

2. A cup of tea cools slowly, but a cup containing the same weight of methylated spirits, starting from the same temperature, cools more quickly. What information can you learn from this?

3. In the compound bar experiment (p. 26) you may assume that the iron and brass bars are heated to the same temperature. If the bars are of equal weight, does each receive the same quantity of heat? Explain carefully.

4. Could a warm room be cooled by spraying a shower of fine drops of water into the air? Explain fully.

5. A wet rag is fastened round the bulb of a thermometer. Describe and explain the subsequent reading of the thermometer. Would you expect the result to be the same if the rag had been soaked in ether?

6. Why are you likely to catch a chill if you wear wet clothing?

7. Some potatoes are cooking in gently boiling water over a gas-ring. Hoping to have them ready five minutes earlier, the cook turns the gas on full. Would this be any advantage? Explain fully.

8. What quantity of heat is necessary to raise the temperature of (*a*) 50 gm. of water from 0° C. to 100° C., (*b*) 100 gm. of water from 20° C. to 80° C., (*c*) 5 lb. of water from 40° F. to 200° F.?

9. How much heat is given out when (*a*) 200 gm. of water cool from 100° C. to 20° C., (*b*) 150 gm. of water cool from 80° C. to 10° C., (*c*) 10 lb. of water cool from 150° F. to 65° F.?

10. A can containing 200 gm. of water at 15° C. is heated by a Bunsen flame. If heat passes from the flame into the water at the average rate of 3400 calories per minute, how long will it be before the water begins to boil?

11. An iron saucepan weighing 750 gm. contains 500 gm. of water at 15° C. If both are heated to 100° C., how many calories are absorbed by (*a*) the saucepan, (*b*) the water?

12. If, in question 10, the boiling water completely turns into steam in a further 32 minutes, the same heat supply being maintained, how many calories are needed to change 1 gm. of boiling water into steam?

## CHAPTER 20

1. When the convection current, in Expt. B (see p. 186) rises, is any heat lost by conduction to cooler particles with which any warm rising particles come in contact? Give reasons for your answer.

2. State three good conductors of heat and specify, for each, one useful practical application.

3. Do you think that water would boil any more quickly if it were a good conductor of heat? Explain fully.

4. Would birds obtain any advantage by ruffling their feathers in very hot weather? If so, give the reason.

5. Do blankets really warm you when you go to bed? Explain.

6. Why is a room much warmer after curtains have been drawn across the windows?

7. An overheated room requires additional ventilation. How would you adjust the windows for this purpose if they were (*a*) of the old, sash type, (*b*) of modern casement design?

8. In Fig. 138 *a* would it be possible to have any radiators below the level of the boiler? Show, if necessary, how to alter the design of the diagram to prove the correctness of your answer.

9. In Fig. 138 *b*, the storage tank may have an electric immersion heater inserted in it. Draw this diagram and indicate by arrows how the arrangement works when the heater is operating and there is no fire under the boiler.

10. The Sikh's turban consists of a skull cap, round which is loosely twined a length of fine muslin. Compare this form of headwear with the pith-helmet as worn by Europeans in tropical countries.

11. Why is it uncomfortable to walk along a tarred road on a hot sunny day?

12. If you were using a glowing electric radiator to warm a room would you place it in the middle of the room or on the hearth near the empty fire grate?

# INDEX

Abdomen, 95
Acids, properties of, 117
Air, composition of, 135
—, pressure of, 123
— sacs, 162
—, weight of, 122
Alkalies, properties of, 119
Alloys, 48, 111
Altimeter, 130
Amœba, 75–77, 160, 212
Animals, differences between plants and, 72
—, warm- and cold-blooded, 184
Aorta, 156, 213
Archimedes' principle, 16
Arteries, 152
Atmosphere, pressure of, 128
Atoms, 112
Auricle, 151, 153, 213

Balance, chemical, 208
—, spring, 7
—, lever, 8
Barograph, 130
Barometer, aneroid, 128
—, mercury, 125
Bimetallic strip, 40
Blood, circulation of, 153–155
—, composition of, 152
—, function of, 154–159
Breathing, 154, 160 *et seq.*
Breezes, land and sea, 177
British Thermal Unit, 172
Bulbs, 83
Burning, 146

Calorie, 171
Calorimeter, 172
Capillaries, 152
Cartilage, 93
Cells, 74, 212
Central heating, 197
Chemical changes, 64–67
Chlorophyll, 73
Climate, influence of sea on, 176
Combustion, 146
Compound, 67
Conduction of heat, 187
Conductors of heat, 189–194
— —, uses of, 193
Convection of heat, 187, 195
Corm, 84
Corpuscles, blood, 151, 152–153
Cranium, 97
Crystals, 58–60

Density, determination of, 17–19
—, meaning of, 11
Diaphragm, 95, 163
Disease, cause of, 158
Dislocation, 103
Distillation, 55

Element, definition of, 67
Elements, list of, 211
Equations, chemical, 114
Evaporation, 54, 181
Expansion, applications of, 39–46
—, coefficient of, 46
— of liquids, 26–28
— of solids, 24–26
— of water, 48

Fertilization, 86
Filtration, 53
Fish, respiration, 160
Floating dock, 22
Flotation, 16, 21
Flower, parts of, 81
Formulæ, building simple, 143
Frog, blood, 151
—, development of, 86–88
—, dissection of, 212
—, internal structure of, 91–92
—, respiration of, 161

Gills, 87, 161
Girdles, 94–99

Hæmoglobin, 156
Heart, 91, 151, 153, 213

Heat and temperature, 24, 177
—, production of, 146
—, transmission of, 185–187
—, units of, 171, 172
Hot water supply, 199
Hydrometer, 19

Intestines, 91
Invar, 40

Joints, 103

Latent heat, 179
Leaves, 79
Levers, bones as, 108
Ligaments, 94
Liver, 91
Living matter, characteristics of, 71
Lungs, 91, 162

Magdeburg hemispheres, 124
Mammals, 94
Matches, 144
Matter, composition of living, 70
—, states of, 1
Measurement of area, 4, 207
— of length, 3
— of weight, 7
Metals, action of acids on, 118
—, characteristics of, 111
Mixtures and compounds, 69
—, separation of, 69
Molecules, 113
Muscles, 104 *et seq.*

Neutralization, 120
Nitrogen, 149–150
Nucleus, 75

Overflow jar, 6
Oxides, 142
Oxygen, 139–142
—, uses of, 148–149

Pancreas, 91, 158
Perennation, 83
Physical changes, 67
Pith-helmet, 205
Plant, general structure of, 79–82
Plasma, 153, 157
Plimsoll line, 21
Properties, chemical, 62
—, physical, 63
Protoplasm, 74

Radiating quality of surfaces, 203
Radiation, 187, 202
—, absorption of, 200
—, reflection of, 202
Regulo, 42
Relative density, 12, 63
Reproduction, 78
— of amœba, 77
— of frog, 86
— of spirogyra, 78
Respiration of animals, 160–166
— of plants, 166–168
Rhizome, 85
Root, 79

Safety-lamp, 204
Salts, 120
Skeleton, human, 95–104
— of frog, 93
Skull, 97
Solubility, 56
Solution, saturated, 56
Solvents, uses of, 52
Specific gravity, determination of, 18
— —, meaning of, 12
Spirogyra, 77–78
Stem, 79
Stomach, 91
Submarine, 21

Temperature, 24
— of human body, 32, 183
—, scales of, 31
—, —, conversion of, 33–35
Tendons, 105
Thermograph, 41
Thermometer, common, 30
—, fixed points of, 31–33
—, special types of, 36–38.
Thermoscope, 202
Tubers, 85

Upthrust, 13

Vacuum flask, 206
Valency, 142, 211
Veins, 152
Ventilation, 197, 199
Ventricle, 152, 154
Vertebra, 98–99
Volume, measurement of liquids, 4
—, — of solids, 6, 13, 208

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